# A COMPARISON OF THE ACOUSTIC CHANGES MADE FROM SPEAKING TO SINGING IN TRAINED PROFESSIONAL SINGING VOICES AND UNTRAINED VOICES

BY

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This dissertation is dedicated to the memory of my father,
Edward William McCann,
who gave me my love of music and the human voice.

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Abstract of Dissertation Presented to the Graduate School
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# A COMPARISON OF THE ACOUSTIC CHANGES MADE FROM SPEAKING TO SINGING IN TRAINED PROFESSIONAL SINGING VOICES AND UNTRAINED VOICES

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Sixteen subjects, four male and four female, classically trained, professional singers and an equal number with untrained voices were matched on the parameters of age, sex and singing voice type. Each subject read a series of CVC syllables imbedded in a sentence containing the vowels /i/, /ɑ/, and /u/. They sang the same vowels at four points (10%, 25%, 50% 90%) within their singing range. In addition they sang "America, the Beautiful". Then they read a passage in which phrases from the song were imbedded. All samples were recorded in a sound treated booth. Each sample was digitized at the rate of 20 kHz..

The samples were analyzed for $F_0$, the presence of and rate of vibrato, jitter, shimmer, formants, harmonics, and power spectrum. The vowel portion of the CVC words was extracted from each signal and analyzed for $F_0$, jitter, and shimmer on the voicing component of the CSL system. A formant history and power spectrum were obtained on each segment to determine the intensity of the formants and the fundamental. The central one second portion of each of the sung vowels were analyzed for vibrato.

Differences were found in the speaking voices of the trained and untrained subjects. They were primarily in the intensity of the fundamental and second formant frequencies. This increase could be due to the increase in respiratory control experienced by singers as a result of their vocal training. The singers had significantly greater intensities across their fundamental and all formant frequencies in their singing voices. The trained voices increased their intensity significantly more than the untrained voices when going from speaking to singing. Results of speaking fundamental frequency, jitter and shimmer showed no significant differences between the groups. In all of these results, however, the vowel spoken or sung could have a significant effect on the outcome.

# CHAPTER 1
# INTRODUCTION

## Background

Although they share the same production mechanism, speaking and singing are physiologically different in many ways. During singing, in contrast to speaking, the breath stream must be managed with greater care, the temporal and acoustic natures of vowels are dissimilar, and inflection patterns are different. In addition, the singer must constantly make extended adjustments within the frequency spectrum to meet the demands of power and pitch. Also, the aesthetics of singing requires "resonance balancing" beyond the needs of the speaking voice (Miller 1992).

Over the years numerous acoustic parameters have been used to study various aspects of the singing and speaking voice. Among those acoustic factors that have been applied to the study of voice are those of fundamental frequency, voice registers, vocal range, formant frequencies, intensity, and vocal perturbation.

### Fundamental Frequency

The fundamental frequency ($F_o$) of a tone is the number of times a waveform is repeated per unit of time. Fundamental frequency is usually stated in Hertz (Hz). In singing, however, vocal tones are frequently expressed in terms of semitones. There are twelve semitones in an octave and doubling a frequency will raise the perceived pitch one octave. On the standard piano, middle C or $C_4$ is 261.6 Hz while $C_0$ is 16.35Hz (Fletcher 1934).

The fundamental frequency of a speaker varies slightly during speech. The normal speaker uses a range of fundamental frequencies to indicate word and sentence stress, and there is an expectation that the person's voice will have the appropriate pitch for the person's age, and sex (Michel and Wendahl, 1971). Therefore, when measuring a speaker's fundamental frequency (SFF), it is best to take an average over task and time. Average SFF can be expressed in terms of the mean, median or modal frequencies. Whether the mean or median is more practical or useful depends on the distribution characteristics of the fundamentals. Generally, the mean is a good average value if the distribution is more or less symmetrical, while the median is a better choice if the values are skewed. Also of interest is the variability of the $F_0$. This can be accounted for simply by stating the range. The range is commonly expressed in semitones in order to adjust for the nature of pitch perception. Although the perceived pitch increases as frequency increases, the relationship is not linear. In order to make a one octave increase in perceived pitch the frequency must double. Therefore the frequency change from $C_2$ (65.4 Hz) to C3 (130.8 Hz) is only 65.4 Hz, the increase from C4 (261.6 Hz) to C5 (523.2 Hz) is four times greater. The reporting of $F_0$ variation in semitones can provide a misleading picture, however, as it is based on extremes. The variability shown in a given sample does not take into account the number of times a certain tone appears in a sample and may be skewed by the production of a high or low tone rarely produced by the speaker. A better measure is the standard deviation (s.d.) which is the average of the distances of values from the mean. The standard deviation of the fundamental frequency is often expressed in semitones as well and referred to as pitch sigma (Baken 1987).

The average speaking fundamental frequency (SFF) in adult males ranges from 84-165 Hz with a standard deviation of 2.5-3.5 semitones. The range is due to such factors as age and speaking task. (Hollien and Jackson, 1973, Horii, 1975). In females, SFF ranges from 127-275 Hz with standard deviations of 2.5-4.5 semitones (Hollien and Paul, 1969, Stoicheff 1981)

## Registers

The full range of tones that can be produced by the human voice covers a number of distinct subgroups known as registers. Not all vocal tones are produced in the same fashion. Different laryngeal configurations and muscles are involved in the production of tones at various sub groups throughout the total vocal range. In order for a group of vocal tones to be classified as a register, according to Baken, they must meet the following requirements:

> 1. A laryngeal register must reflect a specific and distinct mode of laryngeal action. Vocal tract contributions are irrelevant.
> 2. A laryngeal register is produced across a contiguous range of fundamental frequencies.
> 3. The $F_o$ range of any given laryngeal register has little overlap with the $F_o$ range of any other register. (Baken in Sataloff 1991, pp. 30-31)

The majority of tones, and those used most by untrained singers, occur between 75-450 Hz for men and 130-520 Hz for women. This group of tones is often referred to as the modal register (Hollien, 1974). In singing terminology, the modal register includes the "head" and "chest" voices or the "low," "mid," and "high," sub-registers. At the low and high ends of the vocal spectrum are the pulse and loft registers. Hollien has described the pulse register as occurring at the lowest end of an individual's speaking frequency range, approximately 25-80 Hz in men, 18-46 Hz in women (Hollien and Michel, 1968). This register derives its name from the fact that the listener can perceive the discrete laryngeal pulses resulting from the vocal fold vibratory rate. Although the laryngeal tone is always pulsating in nature, the pulses in other registers are usually rapid enough that the ear is able to resolve them into a continuous tone. Other names for this register are "glottal fry" or "strohbass". It is produced with vocal folds that are rather massive in cross section and free of most tension. In fact, Allen and Hollien (1973) feel that the ventricular or false folds may lie against the upper surface of the true vocal folds during this mode of production. At the high end of the scale is the loft register which is sometimes referred to as "falsetto" (275-620 Hz in males, 490-1,130 Hz in females). This register is characterized by a very high degree of tension that causes the vocal folds to become thinner so that there is only a small vertical contact surface (Allen and Hollien, 1973).

### Vocal Range

The range of frequencies a voice is capable of producing is known as that person's vocal range. It is also known as the frequency range of phonation (FRP), vocal pitch range, phonational range or phonational frequency range. It usually consists of the lowest tone in the modal register to the highest falsetto tone. The pulse register is usually not included. The physiological frequency range of phonation (PFRP) refers to tones of any quality that the person is capable of producing. Only those tones which are of a musically acceptable quality are included in a sub category known as the musical frequency range of phonation (MFRP). The PFRP is usually approximately three octaves in both males and females. The average MFRP is two octaves (Britto and Doyle, 1990). Singing voices are usually classified according to which two octave range their voice most closely corresponds. Hirano (1981) graphically illustrates the various voice types as Bass $E_2$-$E_4$, Baritone $G_2$-$G_4$, Tenor $B_2$-$B_4$, Alto $E_3$-$E_5$, Mezzo $G_3$-$G_5$ and Soprano $B_3$-$B_5$ where $C_4$ is the piano middle C(261.63 Hz).

## Formants

The vocal tract, the area from the vocal folds up through the oral and nasal cavities, acts as a resonator for the signals produced by the vocal folds and by supraglottal sources. The vocal tract can be classed as a resonator because the column of air within it can be compressed and shaped. As a resonator, it allows certain frequencies to pass through unimpeded and to emerge with a higher amplitude relative to other frequencies that are attenuated. The signal produced by the vocal folds is a complex, quasi periodic waveform consisting of a fundamental and various harmonic overtones. The vocal tract consists of a number of different resonators. As the signal from the vocal folds passes through these resonators, certain harmonics of the fundamental are emphasized. These resonances of the vocal tract are called formants and their frequencies are called formant frequencies (Denes and Pinson, 1963). Formants are shown graphically as strong peaks in the frequency spectrum. The lowest two formants help to determine the phonetic character of the vowel, while the upper formants determine the personal characteristics of the voice producing them (Peterson and Barney, 1952). We are able to change the resonance characteristics to emphasize different overtones by changing the shape of the vocal tract. These changes in resonance characteristics result in the production of different vowel sounds even though we may be producing them with the same fundamental frequency. In males, the first formant of any vowel usually occurs between 200 and 800 Hz. The second formant varies within a range of 840 to 2290 Hz, while the third occurs between 1690 and 3010 Hz (Peterson and Barney, 1952). The fourth formant frequency is generally in the 2500 to 4000 Hz range and the fifth, 3000 to 4500 Hz. The shorter vocal tract lengths of adult females tend to produce formant frequencies fifteen percent higher than males. Children will produce formant frequencies forty percent higher than adult males on similar vowels (Peterson and Barney, 1952).

Singer's formant. The loudest tone produced by professional male singers is not significantly louder than that produced by nonsingers (Gramming et al 1988b). However, we are able to hear singers more easily than nonsingers, even when accompanied by a loud orchestra. This is possible due to a phenomenon known as the singer's formant. The singer's formant is a prominent spectral envelope appearing in the 2200-3200 Hz range of all vowel spectra sung by all trained singers except sopranos. According to Sundberg (1991), the frequency level of this peak varies depending on the voice classification. It is somewhat lower in frequency for basses and higher for tenors and altos. Sopranos have a lower spectrum level at this peak and it appears to be nothing but a perfectly normal third and fourth formant (Sundberg 1991). Apparently, trained singers are able to achieve this effect by lowering the larynx which allows for the increased resonance of the harmonics in the 2200-3200 Hz band.

## Intensity

We perceive changes in air pressure as sound. The human ear is sensitive to a wide range of pressure variations and can perceive changes that are both very rapid and very small. The magnitude of these pressure changes is perceived as loudness. The physical correlate of loudness is intensity. Intensity is the measure of power per unit area. Acoustic power is measured in watts and acoustic pressure is measured in dynes. The human ear is sensitive to powers ranging from $1 \times 10^{-16}$ W/cm$^2$ for barely audible sounds to $1 \times 10^{-3}$W/cm$^2$ for sounds that are so loud as to cause discomfort or pain to the listener. In practice, intensity levels are expressed in decibels (dB) which is a ratio of one sound's power to a reference power. It is conventional for the reference pressure for the sound pressure level (SPL) to be taken as 0.0002 dynes per square centimeter (d/cm$^2$) at 0 dB which is the threshold of normal hearing, while 200 d/cm$^2$ is equivalent to 120 dB.

The intensity of the voice is produced through the interaction of subglottic pressure and the vocal tract including the glottis. The more adept a person is at increasing his or her lung volume and controlling his or her vocal muscles, the greater the range of his or her intensity. Because of the importance of this interaction, intensity is often dependent on $F_0$. Studies have shown that as $F_0$ increases, intensity tends to increase as well (Colton 1973, Coleman et al. 1977). Coleman and his colleagues tested men and women at 10 percent intervals along their frequency range. At a distance of 6 inches from the subject's lips, a sound level meter measured intensities that ranged from 51-126 dB for men and 48-122 dB for women relative to 0.0002 d/cm$^2$ (Coleman et al. 1977).

## Vocal Perturbation

Production of the voice involves complex neural processes involving aspects of both the central and peripheral nervous systems the result of which is the synchronous operation of the intrinsic and extrinsic laryngeal musculature. Vocal tones generally are not pure or perfectly periodic. Every voice is more or less periodic. The degree of stability of both the temporal and amplitude aspects of the vocal signal provides insight into laryngeal control processes. Possible sources of perturbation include 1) randomness of the action potentials of the laryngeal musculature that create fluctuations in the muscle forces and configuration of the larynx, 2) randomness in the distribution of mucus on the folds and asymmetries in vocal fold structure, 3) randomness of glottal airflow, and 4) changes in articulatory configurations (Titze et al. 1987).

Frequency perturbation (jitter). Frequency perturbation or jitter is a measure of short term variations in fundamental frequency. Jitter is a measurement of how much a given period differs from the period that immediately follows it. One might think that Ideally there should be no difference in fundamental periods except when a speaker purposely changes pitch. However, the resultant voice in that situation would have a very mechanical sound. Therefore, a small amount of jitter is necessary to impart a more vital human quality to the voice. Normal speakers, when speaking at a comfortable pitch and intensity, generally have an average jitter of about one percent or less during the middle portions of sustained phonation (Hollien and Jackson 1973). Larger cycle to cycle differences are associated with longer fundamental periods (Horii, 1979) and pathological speakers can display jitter values that are significantly greater (Horii, 1980).

Jitter is reported in a variety of different ways. Absolute jitter measures are those which ignore the speaker's $F_o$. Lieberman (1961,1963) devised the pitch perturbation factor (PPF) which is the percentage of all perturbations equal to or greater than a half millisecond (0.0005 sec) during steady phonation. Hecker and Kreul (1971) proposed the directional perturbation factor (DPF) which ignores the magnitude of period perturbation and is concerned only with the number of times the frequency change shifts direction. There is a strong correlation between the magnitude of frequency perturbation and mean fundamental frequency.

Larger cycle-to-cycle differences are associated with longer fundamental periods (Horii, 1979). Attempts have been made to compensate for this effect. Honjo and Isshiki (1980) expressed jitter in semitones. The period variability index (PVI) devised by Deal and Emanuel (1978) derives from descriptive statistics. The PVI is actually one thousand times the coefficient of variation of the pitch periods. Their examination of values from twenty normal adult males showed PVI values ranging from 0.4196-0.4951.

During sustained vowels, $F_0$ may undergo slight changes that tend to inflate the jitter measure. Koike's (1973) relative average perturbation (RAP) uses a form of straight-line averaging that reduces the effect of relatively slow changes in $F_0$. The estimated jitter for a single cycle is the difference between its actual period and the mean period for the three cycles of which it is the middle value. Koike found, in his study of 30 adult speakers of both sexes, that the mean frequency RAP was about 0.0046 for /ɑ/. Davis expanded Koike's formula to include deviations from a multipoint average and called it the pitch perturbation quotient (PPQ).

Horii's(1979) jitter ratio is the ratio of mean perturbation to mean waveform duration. Horii found that the jitter ratio for his six male subjects ranged from 5.3-7.6. He also found that this method tends to over-compensate for the change in jitter with the change in fundamental frequency. To adjust for this, Horii (1980) has used jitter in percent which is derived by dividing the mean jitter in milliseconds by the mean period in milliseconds times one hundred. Jitter in percent is essentially the same as Hollien, Michel, and Doherty's (1973) jitter factor. They found jitter factors ranging from 0.33-1.49 for their nine male subjects. They also observed that this measure tends to over compensate for changes in $F_0$. Baken (1987) feels that measures of relative frequency should be expected to be higher in high frequency voices.

Other factors may influence jitter. Jacob (1968) found that jitter ratio tended to decrease with increasing vocal intensity. The vowel produced may also affect the amount of jitter measured. Several researchers have found that high tense vowels, particularly /i/, have significantly greater jitter than laxer vowels, such as /u/ (Horii, 1980, Wilcox and Horii, 1980, Sorenson and Horii, 1983). However, in a study of ten English vowels, Horii (1982) was unable to find any significant differences. Sorenson and Horii (1983) also found a possible gender difference in the amount of jitter. Adult females appear to have more vocal jitter than males.

Amplitude perturbation (shimmer). Amplitude perturbation or shimmer is a measure based on the peak amplitude of each phonatory cycle. Like jitter measures, measurements of shimmer help to describe the short-term instability of the vocal signal. As with jitter, there are several ways to measure shimmer. Hecker and Kreul's (1971) directional perturbation factor (DPF) can also be applied to amplitude measures. Sorenson and Horii (1984) found DPF measures that varied from 43.5-68.3 in males and from 51.3-72.6 in females. The amplitude variability index (AVI) resembles Deal and Emanuel's (1978) period variability index (PVI). It represents the average variation from the mean peak amplitude of the sample. Their examination of values from twenty normal adult males showed AVI values ranging from 0.0216-0.1330. Measuring shimmer in dB has the advantage of freeing the measurement from absolute amplitude. Since dB is already based on a ratio of amplitudes, the ratio used to quantify shimmer need only be that of two consecutive cycles. Horii (1980) found values ranging from 0.37-0.47 dB in males and from 0.19-0.33 dB in females. The Amplitude perturbation quotient (APQ) is similar to Koike's (1973) relative average perturbation(RAP) used in jitter. It uses an eleven point average for smoothing (Takahashi and Koike, 1975, Koike, Takahashi, and Calcaterra, 1977).

## Literature Review

Over the years researchers have compared a number of perceptual and acoustical parameters between trained, experienced voices and untrained voices. The speaking fundamental frequency (Brown et al. 1991), pitch matching accuracy (Murry 1990), ability to perceive changes in intraoral air pressure (Brown et al 1988), vocal shadowing, motor control, phonetogram average sound pressure level (Akerlund et al 1992), breathing, phonation and articulation have all been explored (Gould 1977, Watson and Hixon 1985). Physiologic differences in laryngeal and vocal tract functioning have been found between trained and untrained voices (Sundberg 1987, Schutte and Miller 1983.) The trained singer has been shown to exhibit superior performance in the areas of respiratory control and laryngeal and articulatory dynamics during singing. Others (Watson and Hixon 1985, Shipp and Izdebski 1975) have found no differences between the speaking voices of singers and nonsingers. Brown et al (1988) found that singers have no better oral sensory perception skills in controlling or monitoring intraoral breath pressure than nonsingers.

Brown and his colleagues found that sopranos and tenors exhibited significantly higher speaking fundamental frequency (SFF) levels then did the age matched nonsingers, but the altos and baritones did not differ significantly from the control group. They also found that the professional singers' SFF levels did not vary significantly with age but that those of the nonsingers did (Brown et al 1991). In a subsequent study of 39 professional and 39 nonsinger females, Brown and his colleagues (1993) found that the SFF and intensity levels were significantly higher for the professionals in the older age group only. They also noted that no significant differences were found for mean phonational ranges or habitual pitch levels when the professionals and nonsingers were compared. Murry found that singers are more accurate than nonsingers in their ability to match pitches and that their ability improved over time, whereas the nonsingers did not show a corresponding improvement (Murry 1990).

In a study of pitch perturbation, also known as vocal jitter, Murry and Large (1979) compared the speaking vowels of four female trained singers to their singing vowels and the speaking vowels of five male nonsingers. They found that singers produced lower mean perturbation factors (MPF) and directional perturbation factors (DPF) than did nonsingers. Brown et al (1989 and 1990) found no differences in the spoken vowels of aged female singers when compared to both young and aged female nonsingers.

As intensity and frequency are two aspects of voicing that are often interdependent, the phonetogram, which shows minimum and maximum phonatory sound levels as a function of fundamental frequency, has been used to study singers and nonsingers. The phonetogram records the sound-pressure level of a person's loudest and softest phonations at several frequencies across their phonational range. It is used to show the dynamic extent of a person's voice over his or her frequency range. Gramming and Sundberg (1988), in a spectral analysis of the vowel /a/[1] produced by ten untrained female and ten untrained male singers, found that the fundamental was most often the strongest harmonic partial in soft phonation while in loud phonation the loudest partial was generally an overtone. In a subsequent study of the interdependence of mean fundamental frequencies and mean loudness, Akerlund found that singers (ten trained females), when asked to read a passage at "normal", "loud", and "loudest possible" levels, increased their mean fundamental frequencies and sound pressure levels significantly more from the "normal" than did the nonsingers (ten untrained females). When exposed to conditions of white noise and filtered noise and asked to read loud enough to hear their own voices, a significant increase was noted in the singers from the "normal" condition for the frequency parameter only (Akerlund et al 1992). Gramming et. al.(1988b) did not find any difference between trained and untrained male voices for the same task.

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[1] The /a/ vowel noted was as printed in the Gramming and Sundberg article, however, this could be a mis-print. It was more likely the /ɑ/ vowel.

Awan (1991) used phonetograms to compare trained and untrained vocalists. His results showed that the profiles of trained vocalists demonstrated greater dynamic and $F_0$ ranges, as well as increased vocal area or space between their loudest and softest phonations, when compared with those of untrained vocalists. He also found that the $F_0$ range used in speech by subjects with vocal training was significantly greater than that used by those subjects without vocal training. The trained subjects also had significantly greater mean vocal intensity and intensity ranges than the untrained subjects. He concluded that trained vocalists have more flexibility in terms of vocal frequency for speech than do untrained subjects (Awan 1993).

Spectral analysis of the singing voice has shown that the singers differ from nonsingers in three different aspects. Schutte and Miller (1983) compared two male singers, one trained and one untrained. The trained singer showed a remarkable energy band in the region of 2700 Hz, which corresponds to the area of the singer's formant in males. There was also a clearly discernible vibrato in the trained singer's productions as seen on spectrograms.

Spectrographic analysis of the same singers showed a remarkable difference in the distribution of the partials of the sung vowel. Although they were similar up to 1600 Hz, which provides vowel definition, there was clearly more energy in the partials of the trained singer in the region of the singer's formant. In addition, no partials were registered in the trained voice above 3200 Hz, while the untrained singer had partials discernible as high as 5000 Hz. Schutte and Miller theorized that the trained singer was able to adjust the vocal tract in a way which produces the best distribution of the upper partials in order to concentrate the energy in the singer's formant region while the untrained singer was capable only of adjusting for the appropriate vowel definition.

In a spectral study of a professional tenor, Miller and Franco (1992) found increased acoustic energy in the upper regions of the spectrum that provided the classically trained singer with his characteristic "ring". Similarly, increased presence of acoustic energy in the lower partials of the spectrum in the 500 to 800Hz region gave the singing voice depth. They also noted the presence of vibrato.

## Perspective and Problem

Many studies completed so far comparing singers and nonsingers have either been done on only one voice range or sex and have often looked at just a single acoustic parameter. Singing teachers, speech pathologists and voice scientists are all in need of more information with regard to the way professionally trained singers use their speaking and singing voices as opposed to the way nonsingers use their voices. The singing teachers need to know if their techniques, including the use of imagery, are efficacious and perhaps how they can make these techniques even more effective. The speech pathologists involved with professional voice users need to know whether to generalize the techniques learned by the singer in the vocal studio to his or her speaking voice. The voice scientist needs to know more about the acoustic parameters of speaking and singing, particularly how they change or remain the same, in the same individual, as they switch modes of vocalizing. Sundberg (1990) postulated that such research may eventually lead to a scientific definition of physiologically efficient voice use. Therefore, this study looked at all voice ranges in both sexes (bass/baritone, tenor, alto/mezzo, and soprano) and considered a number of acoustic parameters in both the singing and speaking voices of singers and nonsingers. The acoustic parameters of interest were those which appear to best define the vocal tone (Sundberg, 1990, Miller, 1992). Therefore, it was decided to study the speaking fundamental frequency, the intensity of the fundamental, the intensity of the formant frequencies and the purtabation components, jitter and shimmer. The overall question asked was: "What are the acoustic changes that occur from speaking to singing and are they different for trained singers and nonsingers?"

The following experimental questions were asked:

Question 1: Does vocal training affect the use of $F_0$ during speaking?

Question 2: Does vocal training affect the amount of jitter in the voice during speaking?

Question 3: Does vocal training affect the amount of jitter in the voice during singing?

Question 4: Does vocal training affect the amount of shimmer in the voice during speaking?

Question 5. Does vocal training affect the amount of shimmer in the voice during singing?

Question 6: Does vocal training affect the amplitude of the vowel formants in the voice during speaking?

Question 7: Does vocal training affect the amplitude of the vowel formants in the voice during singing?

# CHAPTER 2
# METHODOLOGY

## Experimental Design and Data Analysis

The purpose of this study was to determine if certain acoustical differences exist between the voices of trained professional singers and the voices of people with no voice training while speaking and singing.

### Subjects

The sixteen subjects of this study were 4 male and 4 female, classically trained, experienced professional singers and a like number of inexperienced or nonsingers matched to the singing subjects in the parameters of age, sex and vocal range. There were two subjects in each of the singing and nonsinging groups for each vocal type of bass (baritone), tenor, alto (mezzo), and soprano. Within each voice classification for both the trained and untrained voices, the subjects were roughly matched for age. Of the two subjects in each voice type, one was in the 24- to 37-year-old age range while the other subject was in the 44- to 52-year-old range. The trained singers had a minimum of five years of formal vocal training, although most had many more, in addition to professional performance experience. The nonsingers had no formal voice training and had rarely, if ever, participated in any kind of organized singing activity or group. All subjects were screened by the experimenter, a licensed speech-language pathologist, to determine if their speech, voice, and hearing were within normal limits and if they were free of any pulmonary disorders. Table 2-1 lists the subjects by age, sex, voice type, singing range and training.

## Methods

Each subject was required to read a series of CVC syllables imbedded in a sentence, such as, "I can say beet again". The CVC syllables contained the vowels /i/, /ɑ/, and /u/. After the reading task was completed each subject's singing range was determined. Each subject was instructed to sing down the scale from middle C (261.6 Hz), presented to the subject from an electronic piano keyboard, to the lowest note they could still produce musically. The middle C was presented again and the subject was instructed to sing up a scale to the highest tone they could produce musically. The procedure was repeated three times to check for consistency and only those notes produced musically all three times were judged as acceptable for inclusion in the singing range of that subject. The number of semitones in the subject's singing range was determined. Then the subject was asked to sing a series of the /i/, /ɑ/, and /u/ vowels at the four notes that corresponded most closely to the ten, twenty-five, fifty and ninety percent points along the subject's singing range. These notes were clearly indicated by markers on the electronic keyboard so that the subjects could cue themselves prior to producing each series of notes. The subjects were asked to sustain each sung vowel for approximately 3 seconds. In addition they read a passage in which phrases from a song with a familiar melody (America, the Beautiful) were imbedded. Then they sang the song "America, the Beautiful". All subjects were instructed to read the sentences and passage at an ordinary conversational level and to sing the sung vowels at the

TABLE 2-1:List of subjects by age, sex, voice type and singing range, in semitones. Means are given for age and singing range. Subjects on the same line were matched by age and voice type.

| TRAINED | | | | | UNTRAINED | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SUBJECT | AGE | SEX | VOICE TYPE | RANGE | SUBJECT | AGE | SEX | VOICE TYPE | RANGE |
| 2E | 49 | M | TENOR | 30 | 1C | 44 | M | TENOR | 24 |
| 3E | 32 | M | BASS | 25 | 3C | 37 | M | BASS | 19 |
| 4E | 52 | M | BASS | 30 | 4C | 47 | M | BASS | 17 |
| 6E | 49 | F | ALTO | 23 | 10C | 45 | F | ALTO | 20 |
| 7E | 28 | F | SOPRANO | 30 | 2C | 30 | F | SOPRANO | 20 |
| 8E | 49 | F | SOPRANO | 30 | 7C | 46 | F | SOPRANO | 26 |
| 9E | 24 | M | TENOR | 21 | 5C | 23 | M | TENOR | 13 |
| 10E | 28 | F | ALTO | 28 | 6C | 27 | F | ALTO | 19 |
| mean | 38.9 | | | 27.1 | | 37.4 | | | 19.8 |
| sd | 10.9 | | | 3.1 | | 8.1 | | | 2.8 |

ten, twenty-five, fifty and ninety percent points of their range and the song, "America the Beautiful", as if they were performing before an audience.

## Instrumentation

The read and sung vowels, the song and the passage were recorded with the subjects standing in a sound treated booth (IAC 124A). A professional unidirectional head-worn dynamic microphone (Shure SM10A) was set at a constant mouth to microphone distance of 7 cm. and at a forty-five degree angle from the center of the lips. A head-worn microphone was chosen in order to allow the subjects the greatest amount of freedom of movement while insuring that the mouth to microphone distance would be consistent throughout the tasks and from subject to subject. All samples were fed to channel one of the CSL$^{tm}$ model 4300 Computerized Speech Lab (Kay Elemetrics Corp.) A-to-D converter board. Prior to the actual recording of each of their four samples, each subject was asked to read or sing a portion of the sample so that an appropriate recording level could be set on the CSL. Care was taken to choose the most appropriate recording level. If a signal is attenuated too much, then information about weaker portions of the signal could be lost. If the input signal is not attenuated sufficiently, then the amplifier would become saturated and information about the peak values in the signal would be lost. Although, typically, loss of peak values appear in a waveform of a sine wave as a flattening of the peak amplitude, this peaking or peak clipping would not be readily recognizable in the complex waveforms of speaking or singing (Baken 1987). Therefore, it was very important to observe the indicator signals carefully throughout the recording process to make sure that peaking did not occur. If peaking of the signal occurred at any time during the recording, the recording level was reset and the sample was re-recorded. At the end of each sample, a

1000 Hz sine wave reference signal was recorded at the same level setting at which the sample was recorded. The tone was produced by a signal generator (Wavetek model 142 HFVCG) and reproduced over a loud speaker(Realistic). The microphone was fixed at the same distance from the speaker as it was from the subject's mouth. The frequency of the tone was verified by a frequency counter (B & K 1820). The intensity of the tone was measured by a sound level meter (Realistic). Each sample was digitized at the rate of 20 kHz. By comparing the intensity of the signal as recorded by the CSL to the intensity of the source signal, as recorded by the sound level meter, the amount of intensity reduction could be calculated. The intensity of the subject's samples could then be determined by adding the amount of intensity reduction to the intensity of the sample as measured by the CSL.

## Analysis

The CSL$^{tm}$ model 4300 Computerized Speech Lab (Kay Elemetrics Corp.) was used to extract $F_o$, formants, harmonics, jitter (in percent) and shimmer (in dB) measures as well as to produce spectrograms of the target vowels and phrases. The samples were analyzed for fundamental frequency ($F_o$), the presence of and rate of vibrato, jitter, shimmer, formants, and power spectrum. The vowel portion of each of the CVC words was extracted from each signal and analyzed separately for speaking fundamental frequency (SFF), jitter, and shimmer by using the voicing component of the CSL system. A formant history and power spectrum were obtained on each segment in order to determine the intensity of each of the formants and the fundamental. The highest intensity within the standard ranges of formant frequencies for each vowel produced was recorded. The formant peaks were usually obvious in the average spectrum of each vowel. In instances where no peak was present, the formant was judged to be missing. In cases where the fundamental frequency was within the range of the first formant, the same intensity was recorded for each. An example of a typical power spectrum is given in figure 2-1.

In addition to the above measures, the central one-second portion of each of the sung vowels were analyzed for vibrato by using the spectrogram function and counting the number of vibrato waves occurring. A sample spectrogram is shown in figure 2-2 with arrows indicating the vibrato waves. Four matching phrases were extracted from the spoken paragraph and the song. These were analyzed for fundamental and any continuous voicing portions were analyzed for jitter and shimmer. Two occurrences of each of the /i/, /ɑ/, and /u/ vowels that occurred in the paragraph and the song were also extracted and analyzed for the same measures as the CVC and sustained sung vowels.

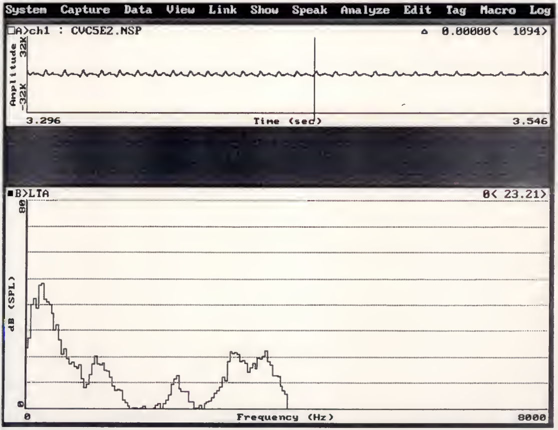

Fig 2-1 Printout of a spoken /u/ vowel as shown on the CSL screen for the long term power spectrum. The six peaks are the intensity of $F_0$ and the five formants.

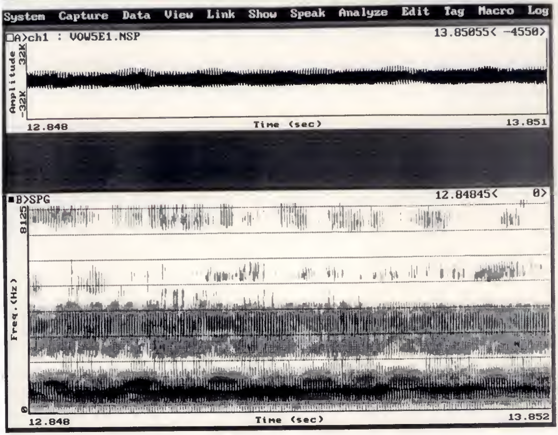

Fig 2-2 Printout of a spectrogram of a one second portion of a sung vowel on the CSL screen. The arrows indicate the peak of the vibrato waves.

# CHAPTER 3
# EXPERIMENTAL RESULTS

The purpose of this study was to determine if certain acoustical differences exist between the speaking and singing voices of both trained professional singers and people with no voice training. Specifically, does vocal training make a difference in a person's speaking fundamental frequency (SFF), and a person's jitter, shimmer, intensity of fundmental frequency or intensity of formant frequencies in both the speaking and singing voices. The acoustic characteristics of eight trained singers, two of each voice type, were compared to those of eight untrained voices, matched to the trained singers according to age, sex, and singing voice type.

## Statistical Analysis

The data set was analyzed in two different ways. Group differences were analyzed using a T-test and an analysis of variance was conducted using a split plot approach. The raw data submitted for analysis are listed in the appendix.

### Analysis of the Results of the Speaking Data

T-test analysis of speaking data. Comparison of the data obtained from the speaking tasks showed no apparent differences between the data obtained from the vowels imbedded in carrier sentences (CVC task) and the vowels taken from the spoken paragraph. Therefore, only the CVC task was submitted to further statistical analysis. When the mean values for the various acoustical variables were compared, some trends emerged. Using the T-test with the assumptions of both equal and unequal variances, the trained and untrained groups were not statistically significant except for the intensity of the first, third and fifth formants. In all three cases, the trained voices' first, third and fifth formants had higher intensities than those of the untrained voices. These results, as well as the results of comparisons between the groups for speaking fundamental frequency, jitter and shimmer, are reported in Table 3-1.

Split plot analysis of speaking data. In order to look for possible interactions among factors in this study, the results were analyzed further using a split plot approach. A split plot is a mixed design as it considers sources of variance that are produced by both within-subject differences and between-subject differences. The various factors considered for analysis are listed in Table 3-2.

Split plot analysis of speaking $F_0$, jitter and shimmer Using the split plot approach, the main effect for vowel was significant for both $F_0$ and jitter (p=0.0001). Figure 3-1 shows a plot of jitter by vowel and training. The effect is accounted for by the significant difference in values between the trained and untrained voices production of the /ɑ/ vowel (p=0.045). The differences between /i/ and /u/ for the trained and untrained voices were not significant. For shimmer, the interaction of vowel and voice type was significant at the 5% level (p=0.0112). This implies that the effect of voice type on shimmer is different for different vowels. Figure 3-2 shows a plot of the shimmer, voice type, vowel interaction. It shows no significant differences among the vowels spoken by tenors and altos; however, the basses and sopranos had /u/ vowels that were significantly different from the other two vowels (p=0.0112). No other main effects or interactions were significant for the factors of jitter, shimmer and $F_0$.

Table 3-1: Number, means, standard deviations, standard error of measurement and p values for trained and untrained speaking voices.

| variable | | n | mean | sd | std error | p values | |
|---|---|---|---|---|---|---|---|
| Fo(in Hertz) | trained | 185 | 186.56 | 83.78 | 6.16 | | |
| | untrained | 188 | 176.58 | 51.43 | 3.75 | unequal | 0.1673 |
| | | | | | | equal | 0.1656 |
| Jitter(in %) | trained | 177 | 0.976 | 1.32 | 0.099 | | |
| | untrained | 178 | 0.83 | 0.92 | 0.069 | unequal | 0.2279 |
| | | | | | | equal | 0.2273 |
| Shimmer(in dB) | trained | 180 | 0.63 | 1.19 | 0.089 | | |
| | untrained | 179 | 0.54 | 0.73 | 0.054 | unequal | 0.3603 |
| | | | | | | equal | 0.3608 |
| Fo Intensity(in dB) | trained | 185 | 73.02 | 5.39 | 0.396 | | |
| | untrained | 189 | 72.36 | 6.64 | 0.483 | unequal | 0.2900 |
| | | | | | | equal | 0.2911 |
| F1 Intensity(in dB) | trained | 185 | 76.91 | 6.82 | 0.501 | | |
| | untrained | 188 | 75.15 | 7.4 | 0.539 | unequal | 0.0174 ** |
| | | | | | | equal | 0.0175 ** |
| F2 Intensity(in dB) | trained | 183 | 65.76 | 11.37 | 0.84 | | |
| | untrained | 188 | 65.13 | 10.62 | 0.775 | unequal | 0.5775 |
| | | | | | | equal | 0.5771 |
| F3 Intensity(in dB) | trained | 185 | 58.09 | 10.59 | 0.779 | | |
| | untrained | 181 | 56.4 | 8.57 | 0.637 | unequal | 0.0943 *** |
| | | | | | | equal | 0.0950 *** |
| F4 Intensity(in dB) | trained | 167 | 53 | 8.32 | 0.644 | | |
| | untrained | 176 | 53 | 8.97 | 0.676 | unequal | 0.9857 |
| | | | | | | equal | 0.9857 |
| F5 Intensity(in dB) | trained | 103 | 42.25 | 7.72 | 0.761 | | |
| | untrained | 141 | 38.91 | 10 | 0.843 | unequal | 0.0036 * |
| | | | | | | equal | 0.0051 * |

***= significant at 0.1 level

**= significant at 0.05 level

*= significant at 0.01 level

Table 3-2: List of factors analyzed for interaction using a split plot design.

- Independent variables
  - between subject
    - Training
      - trained
      - untrained
    - voice type
      - bass
      - tenor
      - alto
      - soprano
  - within subject
    - % of range (singing only)
      - 10
      - 25
      - 50
      - 90
    - vowel
      - /i/
      - /ɑ/
      - /u/
- response variables
  - Fundamental frequency ($F_0$) speaking only
  - jitter (in %)
  - shimmer (in dB)
  - intensity of $F_0$
  - intensity of formants

Table of means for % of jitter for fig. 3-1

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| untrained | 1.31 | 0.52 | 0.64 |
| trained | 1.30 | 0.82 | 0.69 |
| p values | 0.969 | 0.045** | 0.481 |

**= significant at 0.05 level

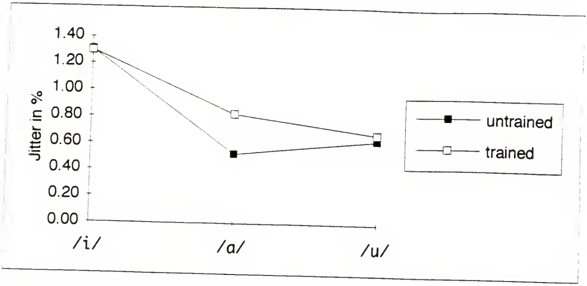

Figure 3-1: Jitter*vowel*training in the speaking voice. The /ɑ/ and /u/ vowels are both significantly different from /i/ at the 0.01 level but not from each other.

Note: the lines on this and the following figures are used only to link variables. They do not indicate a continuum.

Table of means for shimmer for fig. 3-2
Means in the same column that do not share the same letter differ at $p<0.05$.

| vowel/voice | bass | | tenor | | alto | | soprano | |
|---|---|---|---|---|---|---|---|---|
| /i/ | 0.74 | a | 0.57 | a | 0.35 | a | 0.47 | a |
| /a/ | 0.66 | a | 0.64 | a | 0.41 | a | 0.52 | a |
| /u/ | 0.47 | b | 0.46 | a | 0.33 | a | 0.26 | b |

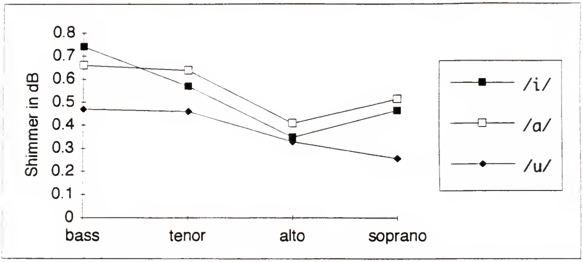

Figure 3-2: Shimmer*vowel*voice type.

Split plot analysis of intensity of speaking $F_0$ and formants. The split plot showed that vowel has a significant effect on $F_0$ intensity as well as the intensities of $F_1$-$F_4$. The interaction of vowel and training and the interaction of vowel and voice type were also significant for the fundamental frequency and all five formants. Since the vowel and training interaction is significant, nothing can be said about the effect of training on the intensity of the formants unless the vowel is held fixed. The data showed that for the /i/ vowel, the trained voices had fundamental frequency and first through third formant intensities that were significantly higher than the untrained voices. The fourth formant was also higher though not significantly so, while the fifth formant was significantly lower. For the /ɑ/ vowel, trained voices had fundamental frequency and first through fifth formant intensities that were higher than those of the untrained voices, although the first and fourth formant intensities were not significantly higher. For the /u/ vowel, trained voices had fundamental frequency, second, fourth and fifth formant intensities that were higher than those of the untrained voices, although the fourth formant intensity was not significantly higher. The first and third formants were lower with the third being significantly so. Plots of the interactions are shown in figures 3-3 to 3-8. The effect of voice type on formant intensity across vowels was also inconsistent. Plots of the interactions are shown in figures 3-9 to 3-14. Table 3-3 lists the p values for the split plot analysis and Table 3-4 lists the p values for the statistical test analysis of the intensity of the individual spoken vowels' $F_0$ and $F_1$-$F_5$ for the trained and untrained groups.

Table of mean intensity levels of Fo for Fig 3-3

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained | 74.29 | 70.45 | 76.17 |
| untrained | 72.03 | 68.94 | 74.81 |
| p values | 0.02 | 0.03 | 0.08 |

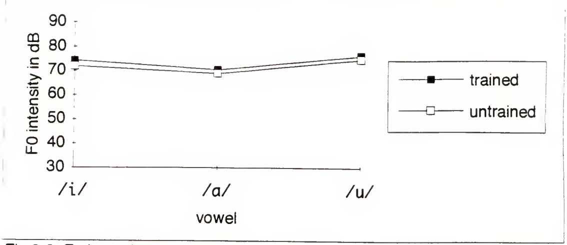

Fig 3-3: Fo intensity* vowel*training(speaking).
For all vowels the trained voices had significantly greater values.

Table of mean intensity levels of F1 for Fig 3-4

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained | 76.38 | 77.00 | 76.58 |
| untrained | 72.76 | 76.90 | 76.81 |
| p values | 0.001 | 0.469 | 0.431 |

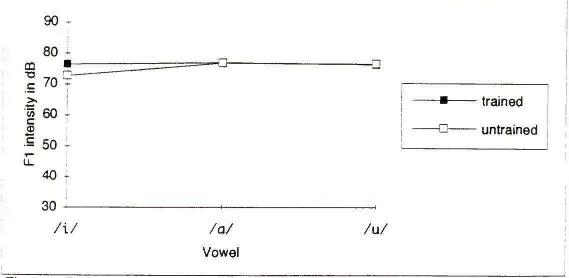

Fig.3-4: F1 intensity*vowel*training(speaking)
The trained voices had significantly greater values for /i/.

Table of mean intensity levels of F2 for Fig 3-5

| | /i/ | /ɑ/ | /u/ |
|---|---|---|---|
| trained | 62.58 | 76.63 | 62.20 |
| untrained | 60.48 | 72.97 | 57.29 |
| p values | 0.078 | 0.001 | 0.004 |

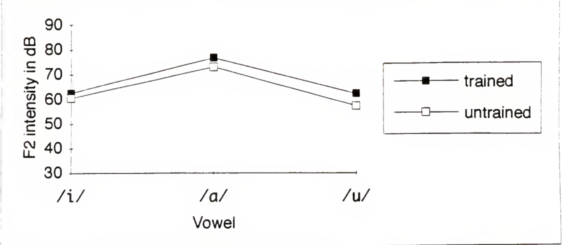

Fig. 3-5: F2 intensity*vowel*training(speaking)
For all vowels the trained voices had significantly greater values.

Table of mean intensity levels of F3 for Fig 3-6

| | /i/ | /ɑ/ | /u/ | |
|---|---|---|---|---|
| trained | 62.61 | 60.47 | 51.02 | |
| untrained | 57.86 | 57.20 | 53.89 | |
| p values | 0.0002 | 0.014 | 0.040# | #=untrained>trained |

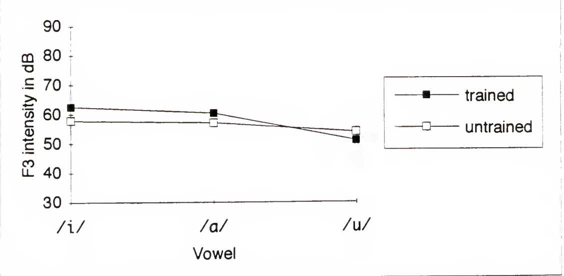

Fig. 3-6: F3 intensity*vowel*training(speaking). The trained voices had significantly greater values for /i/ and /ɑ/ and significantly lower values for /u/.

Table of mean intensity levels of F4 for Fig 3-7

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained | 55.02 | 53.84 | 51.06 |
| untrained | 54.87 | 52.60 | 50.34 |
| p values | 0.91 | 0.224 | 0.67 |

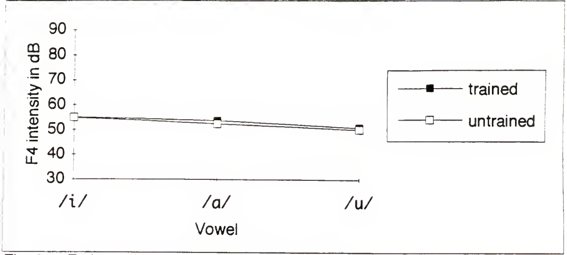

Fig. 3-7: F4 intensity*vowel*training (speaking)
For all vowels, there were no significant differences.

Table of mean intensity levels of F5 for Fig 3-8

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained | 37.85 | 46.58 | 44.05 |
| untrained | 41.85 | 36.52 | 39.15 |
| p values | 0.003# | 0.0002 | 0.015 |

#=untrained>trained

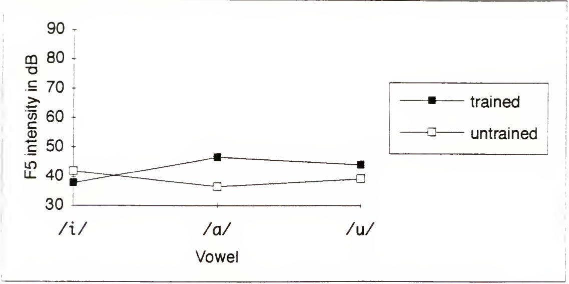

Fig. 3-8: F5 intensity*vowel*training(speaking). The trained voices had significantly greater values for /u/ and / / and significantly lower values for /i/.

Table of mean intensity levels of Fo for Fig 3-9. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| | bass | tenor | alto | soprano |
|---|---|---|---|---|
| /i/ | 73.41 a | 69.78 a | 76.44 a | 73.03 a** |
| /a/ | 69.66 b | 68.03 b | 72.22 b | 68.88 a**,b |
| /u/ | 76.00 c | 72.94 c | 78.41 c | 74.63 c |

**= significant at 0.05 level

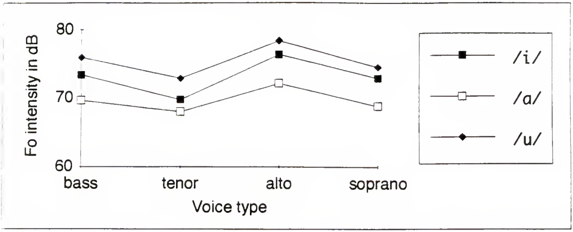

Fig 3-9: Fo intensity*vowel*voice type(speaking)

Table of mean intensity levels of F1 for Fig 3-10. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| | bass | tenor | alto | soprano |
|---|---|---|---|---|
| /i/ | 80.78 a | 72.91 a | 70.38 a | 74.26 a |
| /a/ | 80.47 a | 79.00 b*** | 77.03 b | 73.47 a,b*** |
| /u/ | 79.06 a | 77.09 b***,c | 78.19 b,c | 73.44 b***,c |

***= significant at 0.1 level

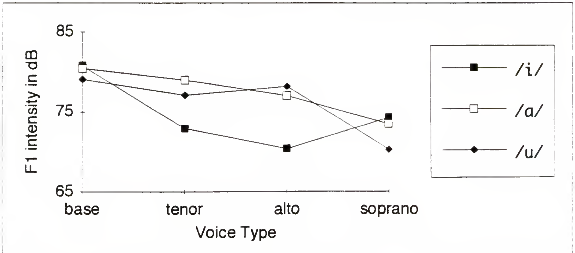

Fig 3-10: F1 intensity*vowel*voice type(speaking).

Table of mean intensity levels of F2 for Fig. 3-11. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| | bass | tenor | alto | soprano |
|---|---|---|---|---|
| /i/ | 64.22 a | 57.47 a | 65.03 a | 59.41 a |
| /a/ | 74.22 b | 74.44 b | 77.66 b | 72.87 b |
| /u/ | 63.94 a,c | 57.06 a,c | 64.53 a,c | 53.20 c |

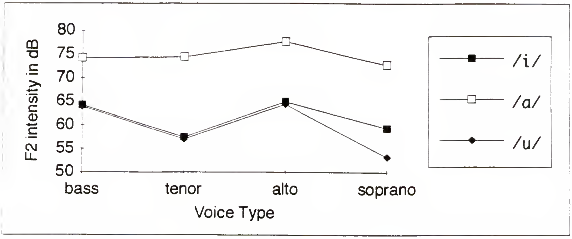

Fig 3-11: F2 intensity*vowel*voice type(speaking).

Table of mean intensity levels of F3 for Fig 3-12. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| | bass | tenor | alto | soprano |
|---|---|---|---|---|
| /i/ | 64.21 a***,c** | 55.69 a,c** | 62.25 a | 59.08 a |
| /a/ | 62.09 a***,b | 56.37 a,b | 60.41 a | 56.47 a |
| /u/ | 59.68 b,c** | 52.41 c** | 50.31 c | 47.41 c |

***= significant at 0.1 level

**= significant at 0.05 level

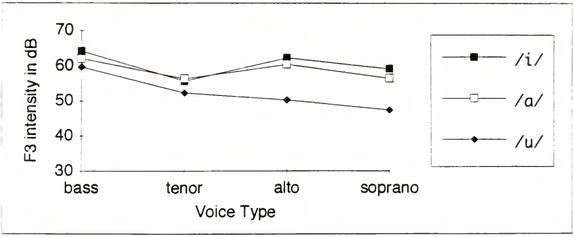

Fig 3-12: F3 intensity*vowel*voice type (speaking).

Table of mean intensity levels of F4 for Fig 3-13. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| | bass | tenor | alto | soprano |
|---|---|---|---|---|
| /i/ | 55.92 a,c** | 57.38 a | 51.44 a | 55.31 a** |
| /a/ | 59.96 a | 54.42 b | 51.56 a | 51.01 a**,c |
| /u/ | 56.94 c** | 52.04 c | 45.97 c | 47.93 c |

**= significant at 0.05 level

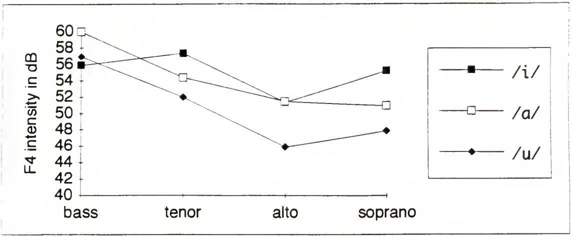

Fig. 3-13: F4 intensity*vowel*voice type (speaking).

Table of mean intensity levels of F5 for Fig 3-14. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| | bass | tenor | alto | soprano |
|---|---|---|---|---|
| /i/ | 36.94 a | 40.63 a | 42.03 a | 37.71 a*** |
| /a/ | 30.63 b | 46.41 b | 45.05 a,b** | 31.71 a***,b** |
| /u/ | 40.91 b,c | 42.51 a | 35.18 b**,c | 50.41 b** |

***= significant at 0.1 level

**= significant at 0.05 level

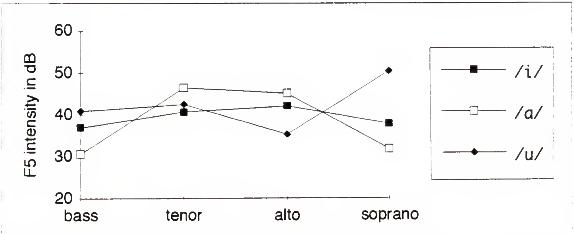

Fig. 3-14: F5 intensity*vowel*voice type (speaking).

Table 3-3: P values for the split plot analysis of speaking data.

| | F0 | JITTER | SHIMMER | INTEN. F0 | INTEN. F1 | INTEN. F2 | INTEN. F3 | INTEN. F4 | INTEN. F5 |
|---|---|---|---|---|---|---|---|---|---|
| TRAINING | 0.6904 | 0.4933 | 0.5309 | 0.6724 | 0.0519*** | 0.8463 | 0.2599 | 0.8024 | 0.2102 |
| VOWEL | 0.0001* | 0.0001* | 0.7396 | 0.0001* | 0.0001* | 0.0001* | 0.0001* | 0.0416** | 0.2789 |
| VOICE TYPE | 0.1478 | 0.8609 | 0.5526 | 0.1406 | 0.0126** | 0.4604 | 0.0724*** | 0.7369 | 0.2295 |
| TRAINING*VOICE TYPE | 0.7635 | 0.8679 | 0.5661 | 0.2219 | 0.1442 | 0.7367 | 0.0701*** | 0.9191 | 0.2468 |
| VOWEL*VOICE TYPE | 0.432 | 0.653 | 0.0112** | 0.0001* | 0.0186** | 0.0001* | 0.0001* | 0.0001* | 0.0001* |
| TRAINING*VOWEL | 0.1039 | 0.9393 | 0.2593 | 0.0116** | 0.0240** | 0.0153** | 0.0027** | 0.0723*** | 0.0002* |

***= significant at 0.1 level
**= significant at 0.05 level
*= significant at 0.01 level

Table 3-4: P values for the statistical test analysis of the intensity of the individual spoken vowels' Fo and F1-F5 for the trained and untrained groups.

| VOWEL | INTENSITY F0 | INTENSITY F1 | INTENSITY F2 | INTENSITY F3 | INTENSITY F4 | INTENSITY F5 |
|---|---|---|---|---|---|---|
| /i/ | 0.02083** | 0.00115* | 0.07767*** | 0.00017* | 0.91 | 0.0034*# |
| /a/ | 0.03446** | 0.46913 | 0.00097* | 0.0137** | 0.22439 | 0.00015* |
| /u/ | 0.0802*** | 0.4307 | 0.00429** | 0.03976**# | 0.67 | 0.01479** |

***= significant at 0.1 level
**= significant at 0.05 level
*= significant at 0.01 level
#= untrained>trained

## Analysis of the Results of the Singing Data

The singing voices of the trained and untrained subjects varied in a number of different ways. The first area of difference was in their singing range. Trained singers had an average singing range of 27.125 semitones while the untrained singers' range was 19.75 semitones. The difference was significant at the 0.01 level. (See Table 2-1 on page 19) The most obvious difference was the presence of vibrato. All of the trained singers had vibrato on all of their sung vowels, while only two of the untrained singers showed any evidence of vibrato. The two untrained singers that displayed vibrato did so for only two to three pulsations (of vibrato) during the one second sample. Of these two, one subject did so on six of the twelve sung vowels and the other subject on three of the twelve sung vowels. This would tend to show that the production of vibrato, for these untrained subjects, was probably an accidental occurrence rather than the result of a conscious effort and/or training as it is in the trained subjects.

T-test analysis of singing data. Comparison of the data obtained from the singing tasks showed no apparent differences between the data obtained from the individually sung vowels and the vowels taken from the song. Therefore, only the individual vowels were submitted to further statistical analysis. When the mean values for the various acoustical variables were compared, some trends emerged. Using the T-test with the assumptions of both equal and unequal variances, the trained and untrained groups were not statistically significantly different except for the intensity of the fundamental frequency and all five formants. In all cases, the trained voices had higher intensities. These results, as well as the results of comparisons between groups for singing jitter and shimmer, are reported in Table 3-5.

Table 3-5: Number, means, standard deviations, standard error of measurement and P values for trained and untrained singing voices.

| variable | | n | mean | sd | std error | p values | |
|---|---|---|---|---|---|---|---|
| Jitter(in %) | trained | 84 | 0.808 | 0.73 | 0.08 | | |
| | untrained | 87 | 0.792 | 0.56 | 0.06 | unequal | 0.8783 |
| | | | | | | equal | 0.8777 |
| Shimmer(in dB) | trained | 84 | 0.297 | 0.17 | 0.019 | | |
| | untrained | 87 | 0.54 | 0.19 | 0.020 | unequal | 0.7990 |
| | | | | | | equal | 0.7992 |
| Fo Intensity(in dB) | trained | 95 | 88.48 | 12.76 | 1.309 | | |
| | untrained | 96 | 76.17 | 6.94 | 0.709 | unequal | 0.0001 * |
| | | | | | | equal | 0.0000 * |
| F1 Intensity(in dB) | trained | 79 | 91.66 | 9.27 | 1.043 | | |
| | untrained | 89 | 78.66 | 7.44 | 0.789 | unequal | 0.0001 * |
| | | | | | | equal | 0.0000 * |
| F2 Intensity(in dB) | trained | 94 | 84.99 | 13.03 | 1.344 | | |
| | untrained | 95 | 67.51 | 11.22 | 1.217 | unequal | 0.0001 * |
| | | | | | | equal | 0.0000 * |
| F3 Intensity(in dB) | trained | 86 | 70.91 | 13.05 | 1.407 | | |
| | untrained | 79 | 55.42 | 9.69 | 1.090 | unequal | 0.0001 * |
| | | | | | | equal | 0.0000 * |
| F4 Intensity(in dB) | trained | 91 | 69.85 | 11.98 | 1.256 | | |
| | untrained | 84 | 51.25 | 9.77 | 1.066 | unequal | 0.0001 * |
| | | | | | | equal | 0.0000 * |
| F5 Intensity(in dB) | trained | 62 | 59.92 | 14.00 | 1.778 | | |
| | untrained | 57 | 43.11 | 10.17 | 1.347 | unequal | 0.0001 * |
| | | | | | | equal | 0.0000 * |

***= significant at 0.1 level

**= significant at 0.05 level

*= significant at 0.01 level

Split plot measure analysis of singing jitter and shimmer. Using the split plot approach, the main effect for vowel was significant for jitter ($p=0.0001$). Figure 3-15 shows a plot of jitter by vowel and training. Again the effect is accounted for by the difference in values between the /i/ vowel and the other vowels. The difference between /ɑ/ and /u/ was not significant. For shimmer, the main effects of voice type, vowel and percent of singing range were all significant ($p=0.0702$, $p=0.0001$, $p=0.0001$). In addition, the interaction of training and vowel was significant ($p=0.0389$). This implies that the effect of training on shimmer is different for different vowels. A closer examination of the results shows that the amount of shimmer in the trained and untrained voices was significantly different for the /u/ vowel only ($p=0.054$). A plot of the interaction (Figure 3-16) shows that, for trained singers, shimmer was greatest on the /i/ vowel, less on /ɑ/ and least on the /u/ vowel. The untrained singers had similar values to the trained singers for /i/, their values for /ɑ/ decreased only slightly, but the values for/u/ were significantly less than those for the /u/ of the trained group ($p=0.06$). The interaction of range and voice type was significant ($p=0.0015$) which shows that the effect of range on shimmer is different for different voice types. A plot of the interaction (Figure 3-17) shows that basses and tenors had the greatest amount of shimmer at 10% of their range, while altos and sopranos showed less difference across percentages of their range. However, no other main effects or interactions were significant for these factors.

Split plot analysis of intensity of singing $F_0$ and formants The split plot showed that training has a significant effect on $F_0$ intensity as well as the intensities of $F_1$-$F_5$. The vowel sung also has a significant effect on $F_0$ intensity as well as the intensities of $F_1$-$F_4$. A closer examination of these interactions

Table of means for % of jitter for fig. 3-15

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| untrained | 1.07 | 0.68 | 0.60 |
| trained | 1.17 | 0.60 | 0.59 |
| p values | 0.685 | 0.407 | 0.928 |

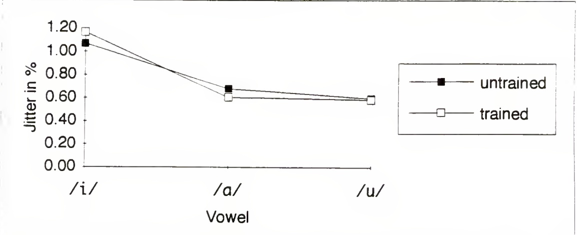

Fig. 3-15: Jitter*vowel*training in the singing voice. The /a/ and /u/ vowels are both significantly different from /i/ at the 0.01 level but not from each other.

Table of means for shimmer for fig. 3-16

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained | 0.37 | 0.30 | 0.22 |
| untrained | 0.36 | 0.34 | 0.15 |
| p values | 0.949 | 0.218 | 0.06 |

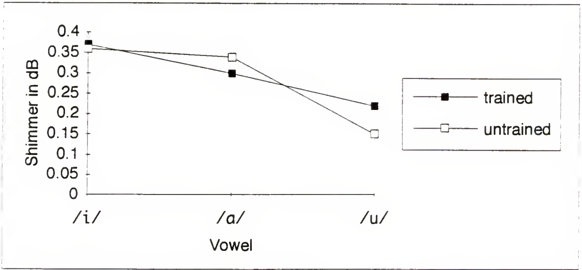

Fig. 3-16: Shimmer*vowel*training(singing)
The trained voices had significantly greater values for /u/ only.

Table of mean shimmer values for fig 3-17. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| range | bass | | tenor | | alto | | soprano | |
|---|---|---|---|---|---|---|---|---|
| 10% | 0.58 | a | 0.51 | a*** | 0.26 | a,b***,c*** | 0.29 | a,b**,c*** |
| 25% | 0.34 | b** | 0.32 | a***,b | 0.24 | a | 0.30 | a,d |
| 50% | 0.26 | c | 0.31 | a***,b | 0.19 | b*** | 0.19 | b**,c*** |
| 90% | 0.26 | b**,c | 0.18 | c | 0.19 | c*** | 0.18 | c***,d |

**=significant at 0.05 level
***=significant at 0.1 level

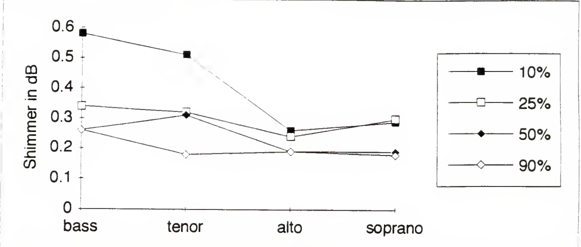

Fig. 3-17: Shimmer*voice type*% of singing range.

Table of mean F5 intensity values for fig 3-18

| | bass | tenor | alto | soprano |
|---|---|---|---|---|
| trained | 67.65 | 56.83 | 51.91 | 69.43 |
| untrained | 36.95 | 48.30 | 40.55 | 50.13 |
| p values | 0.000 | 0.024 | 0.010 | 0.0002 |

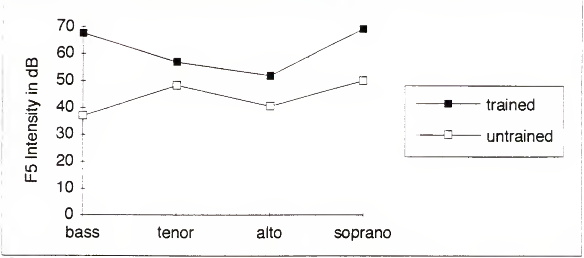

Fig. 3-18: F5 intensity*voice type*training in the singing voice.

showed that the intensity of the trained voices $F_0$ and their $F_1$-$F_5$ were all significantly higher than those for the untrained voices for all vowels. The percent of singing range had a significant effect on all intensities except for that of the fourth formant. The p value results for the split plot are listed in Table 3-6. Other interactions were also significant. The interaction of voice type and training had an effect on the intensity of $F_5$ with all trained voice types having higher intensities in this formant than untrained voice types (figure 3-18). This implies that the effect of training on $F_5$ intensity is different for different voice types. The difference was greatest for bass voices (30.7 dB) and least for alto voices (11.36 dB). The interaction of vowel and percent of range (figure 3-19) and training and percent of range (figure 3-20) both had an effect on the intensity of $F_0$. Intensity increased as percent of singing range increased in both the trained and untrained voices. Trained voices had consistently higher intensities than untrained voices and the difference between the two increased as the percent of range increased. The difference was only 9.67 dB at 10 percent but rose to 17.31 dB at 90 percent. Trained voices also made slight increases in intensity on the sung /ɑ/ and /u/ vowels from the third to forth formant in the area known as the singer's formant (fig 3-21). Such an increase is not seen in the trained voices' spoken vowels or in the untrained voices' spoken or sung vowels (fig 3-22).

There were three areas where interactions were shown for both speaking and singing data. As with speaking, there was an interaction of vowel and voice type on the intensity of $F_0$. Figure 3-23 shows a plot of the interaction for singing while figure 3-24, a reploting of figure 3-9, shows the speaking interaction. The main observation was that the tenors tended to maintain relatively the same intensity across the vowels whether sung or spoken. Other voice types did not

Table 3-6: P values for the split plot analysis of singing data.

| | JITTER | SHIMMER | INTEN. F0 | INTEN. F1 | INTEN. F2 | INTEN. F3 | INTEN. F4 | INTEN. F5 |
|---|---|---|---|---|---|---|---|---|
| TRAINING | 0.7624 | 0.8139 | 0.0196** | 0.0546*** | 0.0585*** | 0.0719*** | 0.0536*** | 0.0162** |
| VOICE TYPE | 0.5177 | 0.0702*** | 0.2839 | 0.9793 | 0.9185 | 0.5835 | 0.8384 | 0.1792 |
| VOWEL | 0.0001* | 0.0001* | 0.0001* | 0.0487** | 0.0001* | 0.0001* | 0.0001* | 0.1068 |
| RANGE | 0.2358 | 0.0001* | 0.0001* | 0.0001* | 0.0001* | 0.0294** | 0.2208 | 0.0041* |
| RANGE*VOWEL | 0.1468 | 0.1885 | 0.0082* | 0.4084 | 0.1603 | 0.2385 | 0.4926 | 0.3270 |
| TRAINING*RANGE | 0.7671 | 0.8457 | 0.0001* | 0.7412 | 0.7394 | 0.8828 | 0.0677 | 0.3976 |
| TRAINING*VOWEL | 0.8781 | 0.0389** | 0.8080 | 0.6397 | 0.0562*** | 0.8164 | 0.5166 | 0.0011* |
| TRAINING*VOICE TYPE | 0.9174 | 0.4815 | 0.1696 | 0.4444 | 0.6902 | 0.5546 | 0.5248 | 0.0385** |
| VOICE TYPE*RANGE | 0.7770 | 0.0015** | 0.0077* | 0.5252 | 0.9349 | 0.0004* | 0.2197 | 0.3768 |
| VOWEL*VOICE TYPE | 0.6670 | 0.1769 | 0.0434** | 0.5127 | 0.3199 | 0.9791 | 0.1882 | 0.0544*** |

***= significant at 0.1 level

**= significant at 0.05 level

*= significant at 0.01 level

Table of mean Fo intensity values for fig 3-19
Means in the same column that do not share the same letter differ at $p<0.05$.

| % of range | 10% | 25% | 50% | 90% |
|---|---|---|---|---|
| /i/ | 75.63 a | 79.24 a | 85.13 a | 92.69 a |
| /a/ | 73.63 b | 77.89 b | 81.00 b | 88.81 b |
| /u/ | 74.94 a | 78.44 a,b | 86.75 c | 94.07 c |

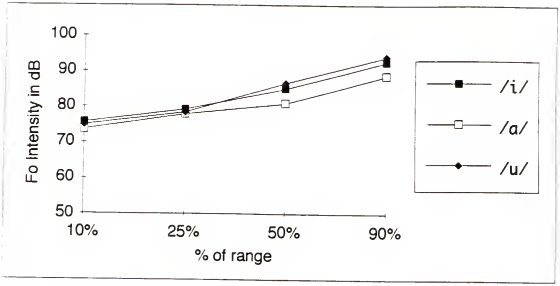

Fig. 3-19: Fo intensity*vowel*% of range (singing). Intensity increased as percent of singing range increased in both the trained and untrained voices.

Table of mean Fo intensity values for fig 3-20

| % of range | 10% | 25% | 50% | 90% |
|---|---|---|---|---|
| trained | 79.63 | 83.63 | 89.67 | 100.4 |
| untrained | 69.96 | 73.59 | 78.55 | 83.09 |
| p values | 0.000042 | 0.000130 | 0.000026 | 0.000002 |

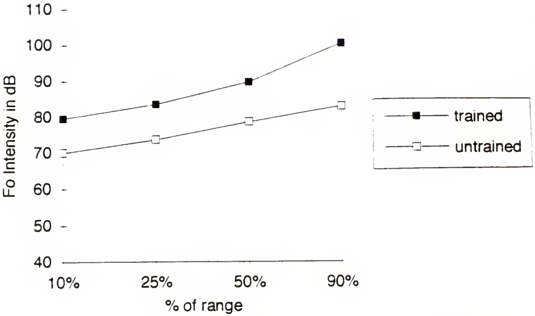

Fig. 3-20: Fo intensity*training*% of singing range. Trained voices had consistently higher intensities than untrained voices and the difference between the two increased as the percent of range increased.

Table of mean intensity levels in trained(T) and untrained(U) voices for Fig. 3-21

| | T/i/ | U/i/ | T/a/ | U/a/ | T/u/ | U/u/ |
|---|---|---|---|---|---|---|
| fo | 92.38 | 73.13 | 89.25 | 69.63 | 92.63 | 74.88 |
| f1 | 92.13 | 72.75 | 93.00 | 74.38 | 93.88 | 76.88 |
| f2 | 79.13 | 56.14 | 92.00 | 69.63 | 88.25 | 64.13 |
| f3 | 74.50 | 54.38 | 71.63 | 49.13 | 65.25 | 50.29 |
| f4 | 70.13 | 49.13 | 72.63 | 47.63 | 66.25 | 48.71 |
| f5 | 56.71 | 34.83 | 67.86 | 37.57 | 60.67 | 43.50 |

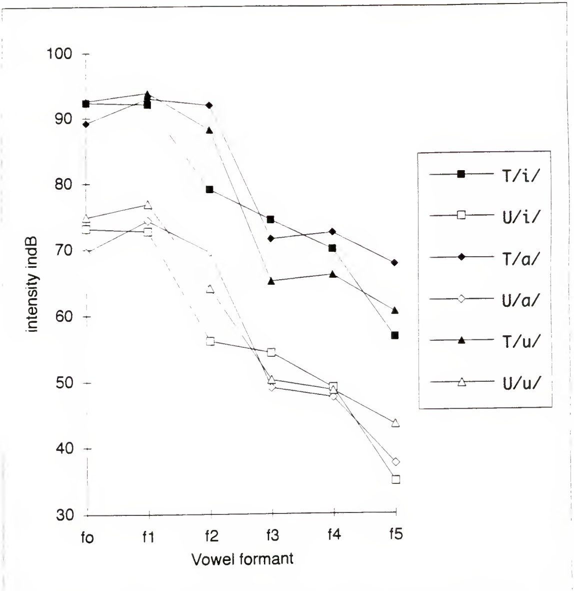

Figure 3-21: Fo and all 5 formant frequencies intensity* vowel *training (singing). Fourth formant increases in intensity more in trained than in untrained in the /ɑ/ and /u/.

Table of mean intensity levels trained(T) and untrained(U) voices for Fig. 3-22

| | T/i/ | U/i/ | T/a/ | U/a/ | T/u/ | U/u/ |
|---|---|---|---|---|---|---|
| fo | 74.29 | 72.03 | 70.45 | 68.94 | 76.17 | 74.81 |
| f1 | 76.38 | 72.76 | 77.00 | 76.90 | 76.58 | 76.81 |
| f2 | 62.58 | 60.48 | 76.63 | 72.97 | 62.20 | 57.29 |
| f3 | 62.61 | 57.86 | 60.47 | 57.20 | 51.02 | 53.89 |
| f4 | 55.02 | 54.87 | 53.84 | 52.60 | 51.06 | 50.34 |
| f5 | 37.85 | 41.85 | 46.58 | 36.52 | 44.05 | 39.15 |

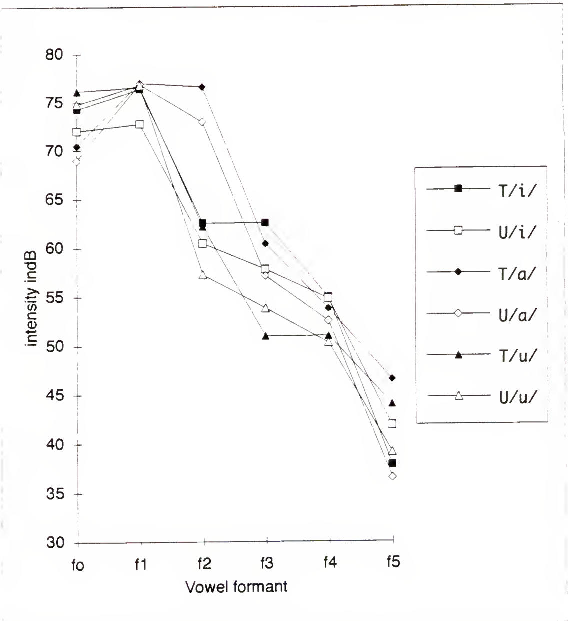

Figure 3-22: Fo and all 5 formant frequency intensity* vowel *training(speech).

Table of mean intensity levels for Fig. 3-23. Means in the same column that do not share the same letter differ at p<0.05.

| | bass | | tenor | | alto | | soprano | |
|---|---|---|---|---|---|---|---|---|
| /i/ | 81.32 | a | 78.81 | a | 84.53 | a | 88.19 | a |
| /ɑ/ | 78.38 | b | 77.44 | b | 80.20 | b | 84.44 | b |
| /u/ | 79.57 | a,b | 79.75 | a | 85.50 | a | 89.03 | c |

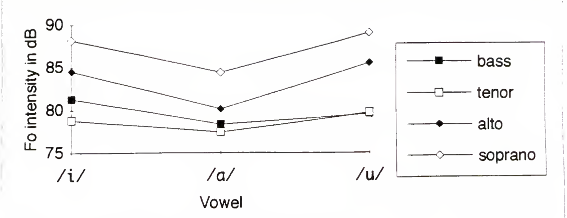

Fig. 3-23: Fo intensity*vowel*voice type (singing)

Table of mean intensity levels for Fig. 3-24. Means in the same column that do not share the same letter differ at p<0.01 unless noted.

| | bass | | tenor | | alto | | soprano | |
|---|---|---|---|---|---|---|---|---|
| /i/ | 73.41 | a | 69.78 | a | 76.44 | a | 73.03 | a** |
| /ɑ/ | 69.66 | b | 68.03 | b | 72.22 | b | 68.88 | a**,b |
| /u/ | 76.00 | c | 72.94 | c | 78.41 | c | 74.63 | c |

**= significant at 0.05 level

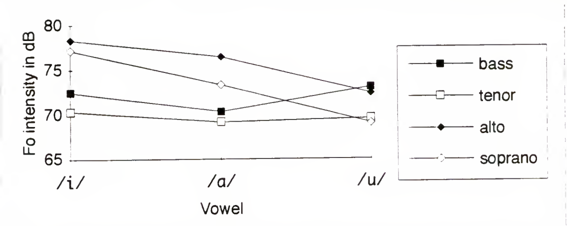

Fig. 3-24: Fo intensity*vowel*voice type (speaking). Tenors tended to maintain relatively the same intensity across the vowels both sung or spoken.

maintain any similar patterns. The interaction of vowel and training had a significant effect on $F_2$, both in speaking and singing. Figure 3-25 shows a plot of the singing interaction which can be compared to figure 3-5 for speaking. The interaction of vowel and training had a significant effect on $F_5$. Figure 3-26 shows a plot of the interaction for singing which can be compared to figure 3-8 for speaking.

### Changes Made from Speaking to Singing

A comparison of the results of speaking and singing data showed some interesting findings. In terms of intensity, untrained voices made little change in their intensity when going from speaking to singing. Trained singing voices, however, were not only significantly louder than the untrained singing voices, they were also louder than their own speaking voices. Figures 3-27 to 3-32 illustrates this difference. An area where trained and untrained voices varied in a similar fashion was in shimmer. Both the trained and untrained voices made a significant reduction in the amount of shimmer across all vowels from speaking to singing. Figure 3-33 illustrates this change.

## Summary

For the speaking data, T-test analysis of both the trained and untrained groups showed they were statistically significant only for the intensity of the first, third and fifth formants. In all three cases, the trained voices' first, third and fifth formants had higher intensities than those of the untrained voices. Split plot analysis of speaking data showed that the vowel spoken has a significant effect on $F_0$, jitter and shimmer. For shimmer, the interaction of vowel and voice type was also significant. The split plot showed that vowel has a significant effect on $F_0$ intensity as well as the intensities of $F_1$-$F_4$. The interaction of vowel and

Table of mean F2 intensity values for Fig. 3-25

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained | 77.55 | 90.28 | 86.97 |
| untrained | 61.58 | 74.41 | 65.69 |
| p values | 0.000014 | 0.000008 | 4.5337E-09 |

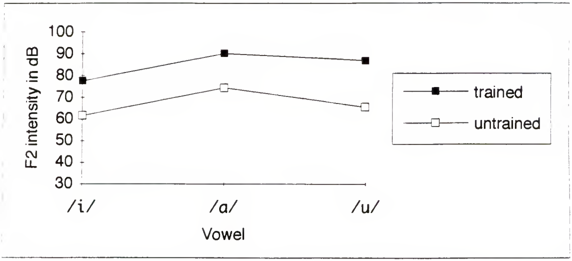

Fig. 3-25: F2 intensity*vowel*training in the singing voice. As with speaking, for all vowels, the trained voices had significantly greater values.

Table of mean F5 intensity values for Fig. 3-26

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained | 54.04 | 65.96 | 59.06 |
| untrained | 43.10 | 43.22 | 42.93 |
| p values | 0.0194 | 0.0003 | 0.0343 |

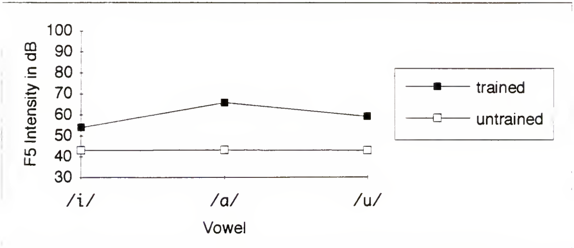

Fig. 3-26: F5 intensity*vowel*training in the singing voice. The trained voices had significantly greater values for all vowels.

Table of mean Fo intensity values for fig. 3-27

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained(speech) | 74.31 | 70.45 | 76.17 |
| untrained(speech) | 71.89 | 68.97 | 74.71 |
| trained(singing) | 92.38 | 89.25 | 92.63 |
| untrained(singing) | 73.13 | 69.63 | 74.88 |

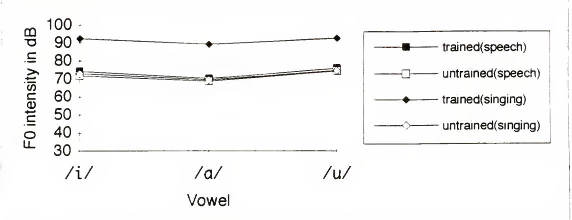

Fig 3-27: Comparison of F0 intensity in speaking and singing*vowel*training
The trained singing voices had significantly greater values across all vowels.

Table of mean F1 intensity values for fig. 3-28

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained(speech) | 76.38 | 77.00 | 76.58 |
| untrained(speech) | 72.63 | 77.00 | 76.75 |
| trained(singing) | 92.13 | 93.00 | 93.88 |
| untrained(singing) | 72.75 | 74.38 | 76.88 |

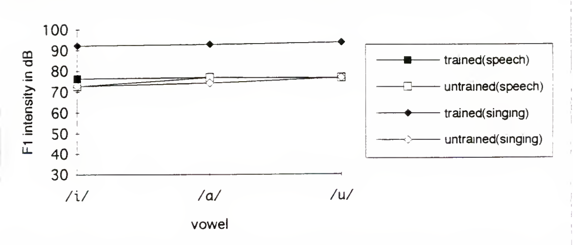

Fig 3-28: Comparison of F1 intensity in speaking and singing*vowel*training
The trained singing voices had significantly greater values across all vowels.

Table of mean F2 intensity values for fig. 3-29

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained(speech) | 62.58 | 76.63 | 62.20 |
| untrained(speech) | 60.60 | 73.10 | 57.46 |
| trained(singing) | 79.13 | 92.00 | 88.25 |
| untrained(singing) | 56.14 | 69.63 | 64.13 |

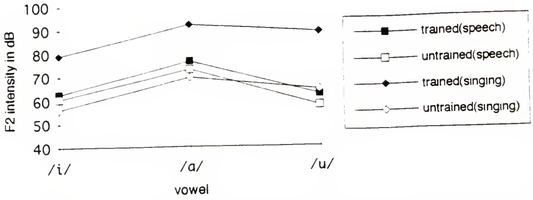

Fig 3-29: Comparison of F2 intensity in speaking and singing*vowel*training
The trained singing voices had significantly greater values across all vowels.

Table of mean F3 intensity values for fig. 3-30

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained(speech) | 62.61 | 60.47 | 51.02 |
| untrained(speech) | 58.00 | 57.30 | 53.94 |
| trained(singing) | 74.50 | 71.63 | 65.25 |
| untrained(singing) | 54.38 | 49.13 | 50.29 |

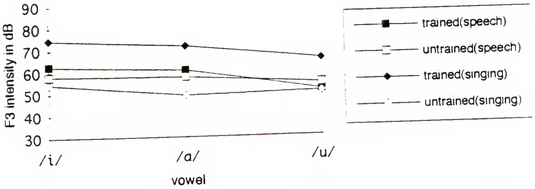

Fig 3-30: Comparison of F3 intensity in speaking and singing*vowel*training
The trained singing voices had significantly greater values across all vowels.

Table of mean F4 intensity values for fig. 3-31

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained(speech) | 55.02 | 53.84 | 51.06 |
| untrained(speech) | 54.98 | 52.61 | 50.51 |
| trained(singing) | 70.13 | 72.63 | 66.25 |
| untrained(singing) | 49.13 | 47.63 | 48.71 |

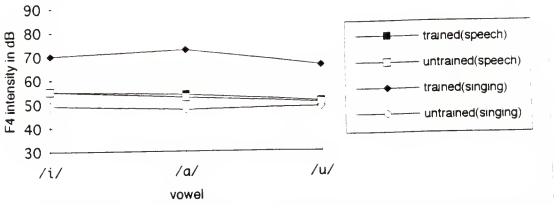

Fig 3-31: Comparison of F4 intensity in speaking and singing*vowel*training
The trained singing voices had significantly greater values across all vowels.

Table of mean F5 intensity values for fig. 3-32

| | /i/ | /a/ | /u/ |
|---|---|---|---|
| trained(speech) | 37.85 | 46.58 | 44.05 |
| untrained(speech) | 41.93 | 36.55 | 39.33 |
| trained(singing) | 56.71 | 67.86 | 60.67 |
| untrained(singing) | 34.83 | 37.57 | 43.5 |

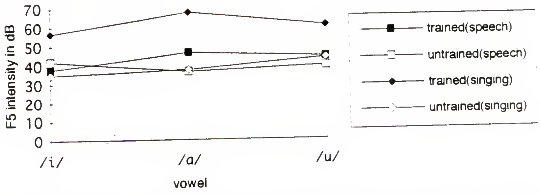

Fig 3-32: Comparison of F5 intensity in speaking and singing*vowel*training
The trained singing voices had significantly greater values across all vowels.

Table of mean shimmer values for fig. 3-33

Means in the same column that do not share the same letter differ at p<0.05.

| | /i/ | | /ɑ/ | | /u/ | |
|---|---|---|---|---|---|---|
| trained(speaking) | 0.575 | a | 0.528 | a | 0.361 | a |
| untrained(speaking) | 0.482 | a | 0.585 | a | 0.383 | a |
| trained(singing) | 0.370 | b | 0.295 | b | 0.221 | b |
| untrained(singing) | 0.359 | b | 0.344 | b | 0.153 | c |

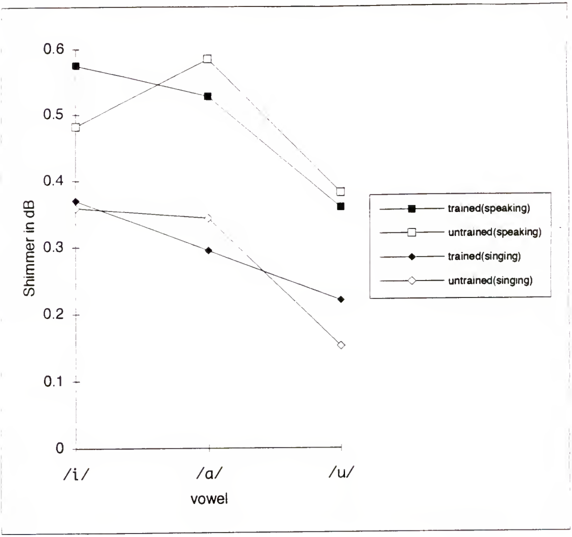

Fig. 3-33: Shimmer*vowel*training in both speaking and singing.
Both trained and untrained voices made a significant reduction in the amount of shimmer across all vowels.

training and the interaction of vowel and voice type were also significant for the fundamental frequency and all five formants. The singing voices of the trained and untrained subjects varied in their singing range, and the presence of vibrato. The T-test showed the trained and untrained groups were statistically significant only for the intensity of the fundamental frequency and the intensity of all five formants. In all cases, the trained voices had higher intensities. Split plot measure analysis of singing showed the main effect for vowel was significant for jitter. For shimmer, the main effects of voice type, vowel and percent of singing range were all significant, as was the interaction of range and voice type. The split plot showed that training has a significant effect on $F_0$ intensity as well as the intensities of $F_1$-$F_5$. The vowel sung also has a significant effect on $F_0$ intensity as well as the intensities of $F_1$-$F_4$. The percent of singing range has a significant effect on all intensities except for that of the fourth formant.

# CHAPTER 4
# DISCUSSION

The purpose of this study was to determine if certain acoustical differences exist between the speaking and singing voices of both trained professional singers and people with no voice training. The overall question asked was: "What are the acoustic changes that occur from speaking to singing and are they different for trained singers and nonsingers?" The acoustic characteristics of jitter, shimmer, and the formant frequencies were examined in both the speaking and singing voices of eight trained, and eight untrained voices. Fundamental frequency ($F_0$) was examined in the speaking voices. The results show that subtle differences do exist between these groups, primarily in the parameter of formant intensity.

## Speaking Data

One of the findings of this study indicated that when all the vowels were pooled together, those vowels produced by trained voices in connected speech had significantly higher intensities in the first, third and fifth formants than those of the untrained voices. However, when the data was checked for interactions, the interactions among the formant intensities, vowel and training were found to be significant. A closer examination of the formant intensities by vowel showed that of the eighteen possible measures of intensity (three vowels times the six intensities of the fundamental and five formants), trained voices had significantly higher intensities on eleven of these measures. Four other measures were also higher in the trained voices but not significantly so. One aspect that was consistent was that the intensity, in both the $F_0$ and the second formant across all three vowels, was significantly higher in trained voices .

The increased intensity shown by trained voices is not surprising when one considers the importance that controlling intensity has to the singer. During training, singers must learn to control not only subglottic pressure but also the stiffness of their vocal folds, the two components most responsible for the modulation of intensity. According to Sundberg (1990), the singer has to learn to tailor subglottic pressure to every note, taking into consideration both its pitch and loudness. He points out that the singer must adjust subglottic pressure accurately or risk errors in pitch. Awan (1993) found that his trained subjects also had significantly greater mean vocal intensity and intensity ranges than the untrained subjects. He theorized that this was due to the fact that vocal training has a beneficial influence on respiratory control. Gould (1977) has shown that as singers progress through their vocal training, they expanded the vital capacity portion of their total lung volume. He assumes "a relationship between the superior vocal ability of the trained singer and a superiority in ventilatory capacity."(pp. 3-4) Bouhuys et al. (1966) reported that as they increase intensity, trained singers actually are able to reduce their rate of air flow while untrained singers producing the same tone required a higher flow rate. Therefore, it is most probable that Gould (1977), when speaking of singers having superior ventilatory capacity was thinking of superior ventilatory control.

Also of interest is the fact that jitter measures when compared across vowels were not significantly different between trained and untrained voices. On the surface, this agrees with the finding of Brown et al (1990) who found no significant difference in the spoken /ɑ/ vowels of aged female singers when compared to both young and aged female nonsingers. However, when the measures for the /ɑ/ vowels recorded in this study were analyzed there was a significant difference between the trained and untrained groups. Murry and Large (1979) found trained female singers had significantly less jitter on the spoken /ɑ/ vowel as compared to untrained males. In this study, where matched pairs of trained and untrained voices were compared, the trained voices had significantly more jitter than did the untrained on the /ɑ/ vowel. There are a number of reasons why results differed among these studies. The difference in results between Brown et al (1990) and this study could be because Brown used a digitizing rate of 16 kHz as compared to 20 kHz in this study. He also used the zero crossing method to extract the period boundaries used in jitter calculations while in this study a peak picking method was used. The CSL software used in this study calculates jitter peak to peak using a relative average perturbation over three periods calculated in percent. Titze and Liang (1993a) report that only the waveform matching method meets the high precision criterion of being able to extract a one percent frequency change. Murry and Large (1979) tape recorded their samples rather than digitizing them and Doherty and Shipp (1988) found that some analog tape recorders can inflate perturbation measures because of seemingly perceptually insignificant variations in the tape speed and/or flutter.

The microphone used in this study was a unidirectional dynamic head-worn microphone set at a forty-five degree angle, seven centimeters from the mouth. Brown et al (1990) used an EV 664 set 28 centimeters from the mouth and Murry and Large (1979) used an EV 664 set 25 centimeters from the mouth. In a study published after the subjects in this study were recorded, Titze and Winholtz (1993b) determined that a cardioid condenser microphone set four centimeters from the mouth had the smallest effect on perturbation measures. However, at the small microphone-to-mouth difference used in this study, the differences in jitter values under similar conditions between Titze's best microphone and one close in type to the one used in this study were no greater than 0.01.

The sample length, particularly for the spoken samples, may not have been long enough. Titze and Horii (1987) recommended 30 cycles and all samples in this study were at least 30 cycles. Karnell (1991), however, recommends a sample of at least 110 cycles with 190 cycles being a better sample size. Given the context of running speech used in this study, such sample sizes would be impossible as the vowel durations were not long enough. Most sung samples in this study were at least 110 cycles except for the lowest bass/baritone notes. Brown et al (1990) used a range of cycles from 69 to 715 cycles depending on the $F_0$ produced. Their mean was 258 cycles and median 243 cycles, respectively. Murry and Large (1979), who were hand counting their cycles used a sample length of 50 cycles. Finally, it just may be that vocal training may or may not have any significant effect on either reducing or increasing jitter.

Jitter measures for both groups on two of the three vowels tested, /ɑ/ and /u/, agreed with those found by previous research to establish norms using a similar jitter measure (Horii, 1980, Hollien and Jackson, 1973). The third vowel, /i/, was significantly different from /ɑ/ and /u/, but there was still no significant difference between the trained and untrained voices (p=0.37). There was a great deal of variation in /i/ productions by both groups (trained: mean=1.30, s.d.=1.01; untrained: mean=1.31, s.d.=1.39) which may account for the differences. Horii used a larger number of subjects, thirty-one males. When means were extracted for just the males in this study, their results still varied from Horii's. The mean for all males in this study on /i/ was 1.10 percent (sd=0.78), still well above Horii's mean of 0.72 percent(sd=0.31).Previous research has found that high tense vowels, particularly /i/, have significantly greater jitter than laxer vowels, such as /u/ (Horii, 1980, Wilcox and Horii, 1980, Sorenson and Horii, 1983). Shimmer measures for all three vowels closely agreed with those found by Horii (1980) and there were no significant differences between the trained and untrained groups on all three spoken vowels.

## Singing Data

The comparison of the singing voices of the trained and untrained subjects showed a number of differences. The significantly greater singing range agreed with the findings of Awan (1991). His results showed that the phonetogram profiles of trained vocalists demonstrated greater dynamic and $F_0$ ranges, as well as increased vocal area or space between their loudest and softest phonations, when compared with those of untrained vocalists. Also from Awan's findings, it was expected that trained singers would be able to produce higher intensities than untrained singing voices particularly at the higher percentages of their singing range. This study supports that finding. The trained singing voices had greater intensities than the untrained singing voices across all vowels and formants and the difference increased as the percentage of singing range increased. As was discussed earlier, this increased intensity could be a product of vocal training. The increased control over the muscles regulating the respiratory system, learned in the vocal studio, enables the singer to increase subglottic pressure ($P_{sg}$) and duration of air flow, both important components of loudness. The presence of vibrato in the trained singers, noted in this study, agreed with the findings of Schutte and Miller (1983). They found a clearly discernible vibrato in the trained singer's productions as seen on spectrograms.

Overall, jitter measures were not significantly different between trained and untrained voices. However, there was a significant difference across all voices between the /i/ vowel and the /ɑ/ and /u/ vowels. There was a slight reduction in the amount of jitter measured for the /i/ vowel from speaking to singing, but this difference was not significant and variation was still large. Shimmer measures again agreed roughly with those found by Horii (1980), although in this study there was a significant difference between the trained and untrained groups on the /u/ vowel. For trained singers, shimmer was greatest on the /i/ vowel, less on /ɑ/ and least on the /u/ vowel. The untrained singers had similar values to the trained singers for /i/, their values for /ɑ/ decreased only slightly, but the values for/u/ were significantly less than those for the /u/ of the trained group.

## Changes Made from Speaking to Singing

Two interesting findings were noted when the task changed from speaking to singing. One is that untrained subjects made little or no increase in intensity as they went from speaking to singing. In fact, on some vowels, intensity decreased. Trained singers, however, had significantly greater intensities across all vowels between their speaking and singing voices. Their production of greater intensities is perhaps an indication of their superior respiratory and laryngeal control. Some of the differences measured may be due to some reticence on the part of the nonsingers. The nonsingers were often hesitant about participating in the study until they were assured that they would not have to sing in front of anyone and that no one would hear their recordings other than the examiner. All of the trained singers on the other hand, had appeared as soloists and had years of experience performing in front of others, be it attentive singing teachers or large audiences.

A finding where trained and untrained voices varied in a similar fashion to each other was in shimmer. Both the trained and untrained voices made a significant reduction in the amount of shimmer across all vowels from speaking to singing. All the mean shimmer values derived in this study, from both speaking and singing, were within the ranges determined by Horii (1980) for these particular vowels. The difference in the speaking and singing values may be due to the longer sample size obtained for the sung vowels versus the spoken vowels. Most sung samples in this study were at least the 110 cycles recommended by Karnell (1991), except for the lowest bass/baritone notes while the spoken samples were 30-to-60 cycles in length.

## Effects on Approaches to Training

This study confirms the advantageous effect of training on the singing voice. Not only did singers have increased singing frequency ranges, they also had significantly greater intensity. It could be that most of these beneficial effects come from the increased control over the muscles of respiration of trained singers resulting in the increased vital capacity noted by Gould (1977). Therefore, training approaches that emphasize increased breath stream control appear to be most effective. More emphasis needs to be placed on having singers apply the skills and muscular control learned in their vocal training to their speaking voices as well. Speech-language pathologists, who deal primarily with the speaking voice, could be of assistance to professional singers in helping them carry over what they have learned in singing to their speaking voices. However, speech-language pathologists who wish to work with professional singers need to have more background in the particular methodologies of singing techniques. They need to increase their knowledge of singing terminology in order to communicate better with their singing clients, and to gain a deeper understanding of what the singing teacher means by his or her terminology. Occasionally, terms are used by both disciplines but have completely different connotative meanings.

## Summary, Conclusions, and Directions for Future Research

The purpose of this study was to determine if certain acoustical differences exist between the voices of trained professional singers and the voices of people with no voice training while speaking and singing. Sixteen subjects, 4 male and 4 female, classically trained, experienced professional singers and a like number of nonsingers were matched to the singing subjects in the parameters of age, sex and singing voice type.

Each subject was required to read a series of CVC syllables imbedded in a sentence, such as, "I can say beet again", containing the vowels /i/, /ɑ/, and /u/. They sang a series of the /i/, /ɑ/, and /u/ vowels at the same pitch at four points (10%, 25%, 50% 90%) within their singing range. In addition they read a passage in which phrases from a song with a familiar melody (America, the Beautiful) were imbedded. Then they sang the song "America, the Beautiful".

The read and sung vowels, the song and the passage were recorded with the subjects standing in a sound treated booth. All samples were fed to channel one of the CSL$^{tm}$ model 4300 Computerized Speech Lab (Kay Elemetrics Corp.) Each sample was digitized at the rate of 20 KHZ.

The CSL$^{tm}$ model 4300 Computerized Speech Lab (Kay Elemetrics Corp.) was used to extract $F_0$, formants, harmonics, jitter and shimmer measures as well as to produce spectrograms of the target vowels and phrases. The samples were analyzed for speaking fundamental frequency (SFF), the presence of and rate of vibrato, jitter, shimmer, intensity of formants, and power spectrum. The vowel portion of each of the CVC words was extracted from each signal and analyzed separately for fundamental frequency ($F_0$), jitter, and shimmer by using the voicing component of the CSL system. A formant history and power spectrum were obtained on each segment in order to determine the intensity of each of the formants and the fundamental.

In addition to the above measures, the central one second portion of each of the sung vowels was analyzed for vibrato by using the spectrogram function of the CSL and counting the number of vibrato waves occurring per second. Four matching phrases were extracted from the spoken paragraph and the song. These were analyzed for fundamental frequency and any continuous voicing portions were analyzed for jitter and shimmer. Two occurrences of each of the /i/, /ɑ/, and /u/ vowels that occurred in the paragraph and the song were also extracted and analyzed for the same measures as the CVC and sustained sung vowels.

In this study, subtle but interesting differences were found in the speaking voices of the trained and untrained subjects. This difference was primarily in the intensity of the fundamental and the second formant frequency. It is felt that this increase is due to the increase in respiratory control gained by singers as a result of their vocal training. The singers had significantly greater intensities across their fundamental and all formant frequencies in their singing voices as well. The trained voices also increased their intensity significantly more than the untrained voices when going from speaking to singing. Results of speaking fundamental frequency, jitter and shimmer showed no significant differences between the groups when vowels were pooled. However, the vowel spoken or sung could have a significant effect on the outcome as jitter results were sometimes significantly different depending on the vowel analyzed. Therefore, it would be essential for future researchers to examine parameters across a wide variety of vowels and to test their results for statistical interactions before reporting results.

The results of this study would indicate that the speaking voices of trained professional singers, or at least the ones studied here, do not vary on many parameters from those of the nonsingers. On the parameters of fundamental frequency, jitter and shimmer, there is no statistical difference between the two groups when more than one vowel is considered. This could be because the trained singers are not carrying over what they have learned in singing to their speaking voices. Singers who do not use some of the vocal techniques during speech that they have learned to apply while singing may be engaging in a form of vocal abuse. This is analogous to a concert pianist having his Steinway finely tuned and then pounding away on it the way he did as a child except for concert performances. It may be that the reason some singers have shortened careers is that they are, in fact, abusing their vocal instrument by not using it during speech as efficiently as they have learned to use it during singing.

Future research in this area should consider a number of factors. Perhaps the group of singing subjects in this study already possessed the slight differences in their speaking voices before vocal training. It would be interesting to sample beginning voice students to see if such differences exist. It would also be useful to follow them through their training to see what changes, if any, occur in their speaking voices. It would also be interesting to record untrained professional singers to see if they also possess these slight differences in their speaking voices. It may be that the differences found here are merely due to regular voice use and lack of vocal inhibition.

In terms of the experimental questions that were asked the following answers were determined

1: Does vocal training affect the use of $F_0$ during speaking? The results of this study show that vocal training does not affect the use of $F_0$ during speaking.

2: Does vocal training affect the amount of jitter in the voice during speaking? This study showed that there was no significant difference between the amount of jitter found in the speaking voices of trained singers and nonsingers except for the /ɑ/ vowel. Nonsingers had significantly less jitter on this vowel only.

3: Does vocal training affect the amount of jitter in the voice during singing? This study showed that there was no significant difference between the amount of jitter found in the singing voices of trained singers and nonsingers.

4: Does vocal training affect the amount of shimmer in the voice during speaking? This study showed that there was no significant difference between the amount of shimmer found in the speaking voices of trained singers and nonsingers.

5: Does vocal training affect the amount of shimmer in the voice during singing? This study showed that there was a significant difference between the amount of shimmer found in the singing voices of trained singers and nonsingers for the /u/ vowel only with nonsingers having significantly less shimmer.

Question 6: Does vocal training affect the amplitude of the vowel formants in the voice during speaking? This study showed that the trained singers had significantly greater intensity than nonsingers for the second formant frequency.

Question 7: Does vocal training affect the amplitude of the vowel formants in the voice during singing? This study showed that the trained singers had significantly greater intensity than nonsingers across all five formants.

# APPENDIX
# DATA FROM SUNG AND SPOKEN VOWELS

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 105.82 | 65 | 72 | 63 | 62 | 62 | * | 1.058 | 0.65 |
| | 95.40 | 63 | 73 | 57 | 59 | 58 | * | 0.883 | 0.349 |
| | 113.80 | 65 | 67 | 60 | 63 | 55 | * | 0.506 | 0.98 |
| | 104.90 | 55 | 58 | 48 | 51 | 48 | * | 0.484 | 1.038 |
| | 104.29 | 65 | 68 | 55 | 59 | 59 | * | 2.98 | 1.834 |
| | 94.79 | 63 | 70 | 57 | 59 | 60 | * | 0.379 | 0.589 |
| | 109.76 | 63 | 60 | 48 | 45 | 48 | * | 0.418 | 0.686 |
| | 92.76 | 55 | 64 | 53 | 52 | 51 | * | 0.309 | 0.437 |
| sum | 821.51 | 494 | 532 | 441 | 450 | 441 | 0 | 7.017 | 6.563 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 100.50 | 66 | 75 | 69 | 54 | 53 | * | 0.503 | 1.121 |
| | 84.86 | 64 | 73 | 72 | 48 | 49 | * | 0.129 | 0.373 |
| | 92.11 | 62 | 67 | 68 | 48 | * | * | 0.368 | 0.449 |
| | 86.46 | 62 | 66 | 62 | 50 | * | * | 0.618 | 0.522 |
| | 92.03 | 62 | 67 | 72 | 55 | * | * | 0.438 | 0.529 |
| | 88.71 | 63 | 68 | 66 | 47 | * | 25 | 0.263 | 0.542 |
| | 90.81 | 64 | 74 | 72 | 52 | * | 25 | 0.605 | 0.914 |
| | 85.47 | 63 | 70 | 71 | 45 | * | 25 | 0.392 | 0.846 |
| sum | 720.93 | 506 | 560 | 552 | 399 | 102 | 75 | 3.316 | 5.296 |
| | | | | | | | | | |
| /u/ | 114.94 | 73 | 80 | 60 | 57 | 58 | * | | |
| | 98.57 | 69 | 79 | 59 | 58 | * | * | 0.394 | 0.274 |
| | 110.29 | 72 | 75 | 62 | 53 | * | * | 0.184 | 0.384 |
| | 99.93 | 70 | 74 | 55 | 45 | * | * | 0.102 | 0.218 |
| | 93.46 | 68 | 72 | 51 | 64 | 63 | * | 0.462 | 0.82 |
| | 99.82 | 69 | 74 | 50 | 58 | 58 | * | 0.259 | 0.538 |
| | 121.21 | 70 | 76 | 55 | 59 | 58 | * | 0.202 | 0.505 |
| | 96.88 | 61 | 66 | 45 | 52 | * | * | 0.294 | 0.424 |
| sum | 835.10 | 552 | 596 | 437 | 446 | 237 | 0 | 1.897 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 1c (tenor). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 211.58 | 79 | 76 | 68 | 69 | 62 | 43 | 3.817 | 1.016 |
| | 206.90 | 79 | 77 | 55 | 57 | 57 | * | 2.150 | 0.718 |
| | 239.16 | 75 | 64 | 63 | 58 | 55 | 37 | 2.206 | 0.996 |
| | 217.69 | 79 | 75 | 64 | 65 | 61 | 44 | 2.208 | 0.481 |
| | 207.42 | 78 | 83 | 63 | 66 | 57 | * | 1.220 | 0.383 |
| | 211.52 | 79 | 81 | 57 | 57 | 55 | 38 | 0.689 | 0.420 |
| | 231.44 | 81 | 75 | 75 | 69 | 68 | 52 | 0.842 | 0.729 |
| | 219.70 | 80 | 76 | 60 | 63 | 59 | 42 | 1.376 | 0.567 |
| sum | 1745.41 | 630 | 607 | 505 | 504 | 474 | 256 | 14.508 | 5.310 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 188.68 | 73 | 70 | 74 | 62 | 60 | 42 | 0.629 | 0.579 |
| | 196.30 | 76 | 69 | 63 | 62 | 54 | 40 | 0.783 | 0.342 |
| | 196.80 | 73 | 77 | 67 | 60 | 54 | 45 | 0.765 | 0.610 |
| | 195.53 | 76 | 79 | 65 | 61 | 55 | 38 | 0.541 | 0.475 |
| | 194.43 | 75 | 76 | 68 | 59 | 49 | 39 | 0.833 | 0.412 |
| | 191.62 | 77 | 80 | 79 | 57 | 50 | 33 | 0.793 | 0.429 |
| | 192.80 | 76 | 86 | 84 | 63 | 61 | 45 | 0.643 | 0.530 |
| | 183.49 | 74 | 77 | 77 | 55 | 52 | * | 0.783 | 0.396 |
| sum | 1539.64 | 600 | 614 | 577 | 479 | 435 | 282 | 5.770 | 3.773 |
| | | | | | | | | | |
| /u/ | 208.04 | 81 | 84 | 60 | 56 | 54 | 50 | 0.892 | 0.316 |
| | 199.60 | 80 | 85 | 62 | 47 | 51 | 46 | 0.832 | 0.194 |
| | 235.85 | 81 | 76 | 61 | 58 | 62 | * | 0.953 | 0.540 |
| | 213.13 | 81 | 84 | 59 | 49 | 51 | * | 0.900 | 0.146 |
| | 207.74 | 77 | 72 | 47 | 56 | 56 | * | 1.077 | 0.294 |
| | 215.25 | 80 | 83 | 49 | 50 | * | * | 0.733 | 0.207 |
| | 242.63 | 79 | 74 | 57 | 56 | 52 | * | 0.747 | 0.446 |
| | 210.66 | 77 | 76 | 49 | 45 | 50 | * | 0.613 | 0.144 |
| sum | 1732.91 | 636 | 634 | 444 | 417 | 376 | 96 | 6.747 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 2c (soprano). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 140.71 | 83 | 85 | 64 | 61 | 56 | 38 | 3.189 | 0.359 |
| | 132.35 | 82 | 83 | 63 | 58 | 50 | 35 | 0.176 | 0.193 |
| | 136.99 | 81 | 82 | 61 | 52 | 50 | 40 | 0.685 | 0.277 |
| | 129.39 | 78 | 81 | 55 | 52 | 49 | 38 | 0.014 | 0.209 |
| | 117.65 | 77 | 83 | 59 | 59 | 44 | 47 | 0.196 | 0.538 |
| | 115.74 | 76 | 79 | 49 | 44 | 43 | 40 | 0.412 | 0.317 |
| | 131.27 | 78 | 79 | 49 | 58 | 46 | 33 | 0.275 | 0.664 |
| | 141.56 | 81 | 81 | 53 | 50 | 48 | 38 | 0.189 | 0.244 |
| sum | 1045.67 | 636 | 653 | 453 | 434 | 386 | 309 | 5.136 | 2.801 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 116.41 | 70 | 79 | 70 | 42 | 47 | 30 | 0.698 | 1.024 |
| | 104.55 | 74 | 78 | 76 | 48 | 38 | 30 | 0.677 | 0.974 |
| | 117.93 | 73 | 77 | 75 | 51 | 54 | 40 | 0.197 | 1.328 |
| | 120.77 | 74 | 78 | 76 | 51 | 53 | 38 | 0.362 | 0.618 |
| | 109.82 | 72 | 77 | 74 | 51 | 45 | 34 | 0.293 | 1.210 |
| | 104.48 | 68 | 73 | 67 | 49 | 49 | 28 | 1.358 | 1.222 |
| | 119.33 | 72 | 82 | 74 | 52 | 45 | 29 | 0.424 | 0.586 |
| | 103.11 | 67 | 71 | 65 | 51 | 52 | 35 | 0.525 | 0.783 |
| sum | 896.40 | 570 | 615 | 577 | 395 | 383 | 264 | 4.534 | 7.745 |
| | | | | | | | | | |
| /u/ | 116.68 | 83 | 82 | 64 | 54 | 45 | 39 | | |
| | 120.12 | 84 | 82 | 58 | 52 | 46 | 40 | 0.240 | 0.298 |
| | 133.00 | 81 | 83 | 58 | 56 | 47 | 38 | | 0.364 |
| | 129.03 | 82 | 82 | 54 | 52 | 44 | 37 | 0.401 | 0.275 |
| | 115.94 | 80 | 75 | 55 | 60 | 45 | 47 | 1.700 | 0.402 |
| | 113.38 | 80 | 78 | 52 | 56 | 41 | 40 | 0.699 | 0.471 |
| | 134.23 | 80 | 80 | 56 | 49 | 47 | 35 | 0.024 | 0.808 |
| | 122.00 | 81 | 81 | 47 | 51 | 41 | 31 | 0.149 | 0.135 |
| sum | 984.38 | 651 | 643 | 444 | 430 | 356 | 307 | 3.213 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 3c (bass). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 149.00 | 69 | 77 | 54 | 44 | 52 | 33 | | |
| | 134.45 | 69 | 72 | 49 | 46 | 52 | 37 | 0.381 | 0.460 |
| | 159.88 | 73 | 73 | 53 | 51 | 54 | 36 | 0.734 | 0.741 |
| | 153.50 | 71 | 72 | 47 | 51 | 53 | 35 | 0.205 | 0.273 |
| | 135.93 | 65 | 71 | 53 | 48 | 52 | 34 | 0.280 | 0.389 |
| | 141.49 | 68 | 72 | 47 | 48 | 48 | 33 | 1.024 | 0.317 |
| | 164.97 | 72 | 69 | 57 | 54 | 57 | 38 | 2.988 | 1.332 |
| | 174.37 | 74 | 70 | 52 | 50 | 49 | 36 | 0.222 | 0.186 |
| sum | 1213.58 | 561 | 576 | 412 | 392 | 417 | 282 | 5.834 | 3.698 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 179.25 | 72 | 75 | 70 | 54 | 54 | 30 | 0.765 | 0.899 |
| | 167.67 | 70 | 77 | 67 | 52 | 42 | 26 | 0.422 | 0.538 |
| | 124.79 | 65 | 74 | 65 | 52 | 50 | 29 | 0.266 | 0.911 |
| | 156.63 | 70 | 74 | 68 | 56 | 46 | 25 | 0.444 | 0.624 |
| | | 69 | 75 | 68 | 53 | 50 | 28 | | |
| | 156.77 | 68 | 71 | 65 | 54 | 54 | 33 | 0.344 | 0.465 |
| | 160.88 | 67 | 77 | 70 | 51 | 51 | 24 | 0.501 | 1.788 |
| | 157.60 | 71 | 75 | 68 | 53 | 53 | 31 | 0.414 | 0.706 |
| sum | 1103.58 | 552 | 598 | 541 | 425 | 400 | 226 | 3.156 | 5.931 |
| | | | | | | | | | |
| /u/ | 176.00 | 78 | 74 | 54 | 56 | 51 | 31 | | |
| | 164.67 | 73 | 75 | 53 | 52 | 55 | 31 | 0.373 | 0.222 |
| | 166.27 | 73 | 74 | 49 | 55 | 54 | 24 | 0.702 | 0.427 |
| | 197.81 | 77 | 73 | 56 | 53 | 47 | 27 | 0.983 | 0.303 |
| | 152.03 | 70 | 70 | 53 | 57 | 54 | 24 | 0.709 | 0.917 |
| | 171.08 | 72 | 72 | 54 | 56 | 50 | 23 | 1.281 | 0.306 |
| | 180.29 | 75 | 76 | 52 | 53 | 52 | 29 | 0.457 | 0.507 |
| | 183.57 | 71 | 68 | 50 | 49 | 49 | 22 | 0.618 | 0.225 |
| sum | 1391.72 | 589 | 582 | 421 | 431 | 412 | 211 | 5.123 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 4c (bass). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 164.08 | 73 | 84 | 75 | 70 | 77 | 53 | 7.827 | 0.374 |
| | 170.60 | 73 | 81 | 70 | 61 | 68 | 43 | 2.287 | 0.319 |
| | 166.11 | 71 | 78 | 71 | 60 | 64 | 43 | | 0.349 |
| | 176.73 | 74 | 71 | 63 | 57 | 63 | 50 | 0.442 | 0.347 |
| | 157.46 | 73 | 79 | 73 | 66 | 70 | 53 | 0.401 | 0.445 |
| | 159.30 | 74 | 82 | 72 | 67 | 69 | 54 | 2.223 | 0.315 |
| | 178.25 | 74 | 80 | 66 | 64 | 64 | 54 | 2.020 | 0.311 |
| | 178.85 | 74 | 81 | 63 | 60 | 63 | 47 | 0.899 | 0.339 |
| sum | 1351.38 | 586 | 636 | 553 | 505 | 538 | 397 | 16.099 | 2.799 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 156.33 | 71 | 92 | 85 | 74 | 67 | 64 | 0.210 | 0.408 |
| | 157.99 | 72 | 92 | 84 | 74 | 67 | 61 | 0.293 | 0.241 |
| | 164.28 | 72 | 84 | 82 | 72 | 65 | 59 | 0.170 | 0.149 |
| | 160.89 | 71 | 87 | 81 | 68 | 60 | 60 | 0.277 | 0.272 |
| | 160.12 | 72 | 85 | 83 | 69 | 70 | 61 | 0.115 | 0.365 |
| | 164.24 | 72 | 89 | 88 | 71 | 64 | 62 | 0.295 | 0.204 |
| | 166.47 | 70 | 86 | 79 | 67 | 59 | 56 | 0.444 | 1.039 |
| | 163.40 | 72 | 85 | 79 | 68 | 60 | 52 | 0.229 | 0.637 |
| sum | 1293.71 | 572 | 700 | 661 | 563 | 512 | 475 | 2.033 | 3.315 |
| | | | | | | | | | |
| /u/ | 165.00 | 74 | 90 | 62 | 63 | 58 | 44 | | |
| | 168.00 | 77 | 88 | 61 | 61 | 53 | 50 | | |
| | 165.00 | 72 | 87 | 70 | 56 | 53 | 50 | | |
| | 166.67 | 74 | 78 | 91 | 72 | 65 | 55 | 0.389 | 0.448 |
| | 175.52 | 76 | 86 | 59 | 68 | 62 | 46 | 0.635 | 0.224 |
| | 175.00 | 75 | 89 | 62 | 67 | 62 | 47 | | |
| | 175.00 | 77 | 88 | 57 | 57 | 60 | 47 | | |
| | 185.19 | 75 | 86 | 53 | 57 | 55 | 37 | 0.268 | 0.188 |
| sum | 1375.37 | 600 | 692 | 515 | 501 | 468 | 376 | 1.292 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 5c (tenor). Stars(*) indicate missing values.

|  | freq |  | intensity |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 238.81 | 75 | 66 | 63 | 57 | 50 | 38 | 0.341 | 0.382 |
|  | 235.88 | 75 | 62 | 62 | 56 | 47 | 38 | 0.231 | 0.231 |
|  | 254.00 | 74 | 65 | 67 | 64 | 54 | 35 | 3.388 | 0.962 |
|  | 245.84 | 74 | 64 | 63 | 59 | 51 | 28 | 0.444 | 0.504 |
|  | 216.14 | 73 | 72 | 57 | 49 | 45 | 32 | 4.101 | 0.233 |
|  | 224.72 | 75 | 69 | 61 | 52 | 44 | 38 | 1.732 | 0.240 |
|  | 257.43 | 76 | 65 | 79 | 67 | 58 | 40 | 0.429 | 0.404 |
|  | 277.59 | 76 | 65 | 70 | 65 | 55 | 38 | 0.514 | 0.416 |
| sum | 1950.39 | 598 | 528 | 522 | 469 | 404 | 287 | 11.180 | 3.372 |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| /a/ | 211.27 | 64 | 73 | 70 | 51 | 30 | 42 | 0.515 | 0.579 |
|  | 217.84 | 67 | 80 | 78 | 57 | 48 | 38 | 0.373 | 0.349 |
|  | 224.81 | 68 | 75 | 76 | 58 | 42 | 34 | 0.420 | 0.386 |
|  | 241.98 | 67 | 72 | 76 | 59 | 44 | 39 | 0.634 | 0.324 |
|  | 201.29 | 65 | 74 | 75 | 54 | 49 | 37 | 0.419 | 0.594 |
|  | 201.34 | 67 | 73 | 75 | 56 | 49 | 44 | 0.258 | 0.359 |
|  | 229.28 | 69 | 82 | 79 | 58 | 44 | 36 | 0.446 | 0.336 |
|  | 306.12 | 71 | 77 | 77 | 57 | 43 | 34 | 0.615 | 0.379 |
| sum | 1833.93 | 538 | 606 | 606 | 450 | 349 | 304 | 3.680 | 3.306 |
|  |  |  |  |  |  |  |  |  |  |
| /u/ | 257.14 | 77 | 69 | 57 | 48 | 49 | 39 | 0.804 | 0.496 |
|  | 252.78 | 75 | 74 | 59 | 48 | 46 | 33 | 0.815 | 0.299 |
|  | 262.99 | 78 | 70 | 62 | 50 | 38 | 29 | 0.554 | 0.315 |
|  | 269.20 | 78 | 68 | 63 | 42 | 37 | 31 | 0.808 | 0.220 |
|  | 221.36 | 75 | 71 | 59 | 57 | 56 | 35 | 0.307 | 0.348 |
|  | 266.48 | 76 | 62 | 60 | 56 | 50 | 33 | 1.370 | 0.339 |
|  | 247.99 | 75 | 71 | 60 | 64 | 50 | 29 | 0.735 | 0.154 |
|  | 230.37 | 74 | 72 | 59 | 55 | 54 | 26 | 0.576 | 0.238 |
| sum | 2008.30 | 608 | 557 | 479 | 420 | 380 | 255 | 5.969 | 0.573 |
|  |  |  |  |  |  |  |  |  |  |

Raw data of spoken vowels from subject 6c (alto). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 173.01 | 62 | 68 | 55 | * | 49 | * | 2.115 | 0.258 |
| | 143.81 | 56 | 72 | 61 | * | 53 | * | 0.273 | 0.395 |
| | 194.93 | 65 | 64 | 62 | * | * | * | 0.325 | 0.368 |
| | 199.12 | 58 | * | 55 | * | * | * | 0.695 | 0.241 |
| | 150.70 | 57 | 70 | 61 | * | 55 | * | 0.167 | 0.560 |
| | 156.86 | 61 | 67 | 56 | * | 53 | * | 1.538 | 0.491 |
| | 201.23 | 64 | 65 | 63 | * | 60 | * | 0.608 | 0.486 |
| | 169.28 | 61 | 66 | 57 | * | 55 | * | 2.294 | 0.253 |
| sum | 1388.93 | 484 | 472 | 470 | 0 | 325 | 0 | 8.015 | 3.052 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 175.53 | 62 | 79 | 74 | 58 | 56 | 21 | 0.332 | 0.161 |
| | 149.54 | 58 | 74 | 67 | 56 | 49 | 21 | 0.473 | 0.351 |
| | 184.05 | 60 | 74 | 70 | 61 | * | 31 | 0.484 | 0.580 |
| | 150.92 | 55 | 74 | 70 | 61 | 61 | 29 | 0.371 | 0.324 |
| | 175.63 | 62 | 74 | * | 63 | 55 | 25 | 0.800 | 0.401 |
| | 147.36 | 57 | 73 | 66 | 62 | 67 | 19 | 0.322 | 0.387 |
| | 196.69 | 60 | 79 | 75 | 59 | 56 | 20 | 0.598 | 0.642 |
| | 143.66 | 55 | 71 | 66 | 60 | 54 | 26 | 0.421 | 0.444 |
| sum | 1323.37 | 469 | 598 | 488 | 480 | 398 | 192 | 3.801 | 3.290 |
| | | | | | | | | | |
| /u/ | 226.67 | 66 | 70 | 53 | 54 | 46 | 59 | 0.957 | 0.238 |
| | 147.99 | 58 | 72 | 51 | 53 | 51 | 53 | 0.674 | 0.237 |
| | 247.25 | 71 | 72 | 56 | 49 | 34 | 47 | 0.973 | 0.174 |
| | 178.78 | 62 | 73 | 52 | 51 | 46 | 49 | 0.458 | 0.196 |
| | 152.01 | 58 | 72 | * | 60 | 58 | 55 | 0.296 | 0.419 |
| | 154.66 | 59 | 71 | * | 56 | 55 | 52 | 0.589 | 0.404 |
| | 254.07 | 72 | 69 | 51 | 43 | * | 44 | 0.552 | 0.231 |
| | 179.67 | 62 | 69 | 49 | 51 | 50 | 49 | 0.958 | 0.127 |
| sum | 1541.11 | 508 | 568 | 312 | 417 | 340 | 408 | 5.457 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 7c (soprano). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 238.68 | 78 | 74 | 65 | 63 | 54 | 54 | 3.79 | 0.268 |
| | 222.95 | 78 | 72 | 59 | 56 | 45 | 45 | 1.495 | 0.309 |
| | 263.94 | 79 | 72 | 65 | 61 | 42 | 42 | 1.214 | 0.339 |
| | 251.43 | 79 | 72 | 70 | 66 | 53 | 53 | 0.442 | 0.325 |
| | 243.19 | 78 | 77 | 63 | 65 | 57 | 56 | 0.444 | 0.298 |
| | 235.92 | 79 | 72 | 60 | 56 | 52 | 49 | 1.239 | 0.337 |
| | 254.16 | 77 | 68 | 73 | 64 | 62 | 50 | 0.8 | 0.289 |
| | 222.94 | 73 | 73 | 60 | 55 | 52 | 45 | 3.773 | 0.605 |
| sum | 1933.22 | 621 | 580 | 515 | 486 | 417 | 394 | 13.197 | 2.77 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 218.28 | 76 | 81 | 74 | 58 | 54 | 35 | 1.139 | 0.334 |
| | 212.04 | 75 | 78 | 69 | 55 | 52 | * | 0.489 | 0.388 |
| | 241.74 | 76 | 81 | 85 | 63 | 52 | 43 | 1.353 | 0.65 |
| | 228.66 | 77 | 82 | 77 | 61 | 52 | 38 | 0.742 | 0.316 |
| | 217.20 | 75 | 76 | 77 | 61 | 53 | 38 | 1.243 | 0.991 |
| | 218.58 | 76 | 74 | 67 | 53 | 52 | * | 0.39 | 0.375 |
| | 239.44 | 76 | 84 | 78 | 62 | 55 | * | 0.833 | 0.802 |
| | 227.27 | 74 | 75 | 68 | 57 | 49 | * | 0.473 | 0.348 |
| sum | 1803.21 | 605 | 631 | 595 | 470 | 419 | 154 | 6.662 | 4.204 |
| | | | | | | | | | |
| /u/ | 245.86 | 80 | 80 | 73 | 48 | 42 | 40 | 0.969 | 3.504 |
| | 232.75 | 81 | 81 | 64 | 45 | 40 | 37 | 0.494 | 0.168 |
| | 272.29 | 83 | 83 | 68 | 52 | 49 | 34 | 0.469 | 0.249 |
| | 252.12 | 80 | 80 | 65 | 48 | 46 | * | 0.633 | 0.154 |
| | 246.03 | 83 | 83 | 51 | 55 | 49 | 37 | 0.58 | 0.246 |
| | 229.08 | 81 | 81 | 64 | 53 | 50 | * | 0.636 | 0.17 |
| | 261.76 | 80 | 80 | 61 | 43 | 41 | * | 0.488 | 0.315 |
| | 217.34 | 76 | 76 | 54 | 43 | 34 | * | 1.207 | 0.247 |
| sum | 1957.22 | 644 | 644 | 500 | 387 | 351 | 148 | 5.476 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 10c (alto). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | f0 | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 161.07 | 73 | 65 | 49 | 44 | 56 | 38 | 3.007 | 1.346 |
| | 112.66 | 63 | 75 | 54 | 49 | 55 | 38 | 0.938 | 0.477 |
| | 172.66 | 74 | 67 | 49 | 49 | 56 | 37 | 1.367 | 1.061 |
| | 150.04 | 71 | 69 | 49 | 51 | 54 | 39 | 0.972 | 0.428 |
| | 148.00 | 73 | 71 | 51 | 51 | 56 | 32 | 0.781 | 1.013 |
| | 135.01 | 68 | 73 | 52 | 52 | 56 | 41 | 0.525 | 0.239 |
| | 163.93 | 74 | 70 | 52 | 56 | 61 | 40 | 1.863 | 1.409 |
| | 135.71 | 70 | 70 | 49 | 51 | 55 | 37 | 0.910 | 0.454 |
| sum | 1179.08 | 566 | 560 | 405 | 403 | 449 | 302 | 10.363 | 6.427 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 123.16 | 69 | 79 | 77 | 46 | 47 | 51 | 1.418 | 0.770 |
| | 114.94 | 66 | 77 | 74 | 46 | 51 | 47 | 0.383 | 0.973 |
| | 176.80 | 65 | 71 | 65 | 54 | 49 | 38 | 0.344 | 0.495 |
| | 118.12 | 67 | 76 | 69 | 50 | 50 | 46 | 7.418 | 3.705 |
| | 121.07 | 69 | 73 | 64 | 51 | 48 | 41 | 1.824 | 1.261 |
| | 132.13 | 71 | 73 | 72 | 56 | 53 | 50 | 3.957 | 0.710 |
| | 145.35 | 69 | 79 | 81 | 49 | 56 | 51 | 0.373 | 0.356 |
| | 124.65 | 67 | 78 | 70 | 50 | 50 | 45 | 3.376 | 0.386 |
| sum | 1056.22 | 543 | 606 | 572 | 402 | 404 | 369 | 19.093 | 8.656 |
| | | | | | | | | | |
| /u/ | 159.74 | 74 | 72 | 52 | 44 | 51 | 32 | * | * |
| | 115.77 | 68 | 74 | 45 | 40 | 49 | 49 | * | * |
| | 179.43 | 76 | 75 | 50 | 43 | 53 | 47 | * | 0.192 |
| | 99.35 | 66 | 72 | 51 | 46 | 52 | 53 | 0.389 | 0.198 |
| | 128.88 | 71 | 71 | 53 | 54 | 42 | 38 | 0.635 | 0.973 |
| | 134.77 | 68 | 71 | 48 | 42 | 43 | 42 | * | 0.951 |
| | 180.51 | 74 | 76 | 55 | 45 | 52 | 50 | * | 0.512 |
| | 160.00 | 69 | 70 | 46 | 44 | 39 | 41 | 0.268 | 0.268 |
| sum | 1158.46 | 566 | 581 | 400 | 358 | 381 | 352 | 1.292 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 2e (tenor). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | f0 | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 127.59 | 78 | 89 | 80 | 84 | 76 | * | 0.319 | 1.206 |
| | 133.45 | 71 | 82 | 76 | 82 | 73 | * | 1.631 | 0.937 |
| | 156.99 | 70 | 79 | 69 | 65 | 67 | * | 0.959 | 2.626 |
| | 141.70 | 71 | 81 | 77 | 75 | 76 | * | 0.590 | 0.436 |
| | 134.33 | 72 | 82 | 73 | 78 | 64 | * | 1.247 | 1.098 |
| | 131.58 | 71 | 83 | 65 | 75 | 60 | * | * | 2.981 |
| | 158.31 | 74 | 84 | 72 | 75 | 64 | * | 0.668 | 1.297 |
| | 227.89 | 76 | 76 | 75 | 64 | 59 | * | * | 0.276 |
| sum | 1211.83 | 583 | 656 | 587 | 598 | 539 | 0 | 5.414 | 10.857 |
| | | | | | | | | | |
| | 115.73 | 66 | 72 | 85 | 69 | 73 | * | 0.236 | 0.722 |
| /a/ | 119.12 | 66 | 72 | 87 | 70 | 75 | * | 0.282 | 0.236 |
| | 131.98 | 67 | 71 | 89 | 75 | 71 | * | 0.448 | 0.280 |
| | 134.38 | 69 | 74 | 91 | 75 | 80 | * | 0.518 | 0.356 |
| | 130.48 | 68 | 72 | 88 | 70 | 74 | * | 0.304 | 0.284 |
| | 115.56 | 70 | 75 | 88 | 68 | 76 | * | 0.358 | 0.710 |
| | 129.15 | 68 | 71 | 84 | 69 | 71 | * | 0.344 | 0.356 |
| | 186.72 | 68 | 70 | 82 | 63 | 64 | * | 0.044 | 0.386 |
| sum | 1063.11 | 542 | 577 | 694 | 559 | 584 | 0 | 2.534 | 3.330 |
| | | | | | | | | | |
| /u/ | 131.58 | 70 | 77 | 63 | 51 | 53 | 50 | * | * |
| | 138.00 | 71 | 78 | 62 | 54 | 50 | 42 | * | * |
| | 184.90 | 75 | 84 | 68 | 53 | 55 | 57 | * | 0.192 |
| | 175.79 | 75 | 83 | 72 | 48 | 47 | 47 | 0.389 | 0.198 |
| | 136.13 | 73 | 77 | 50 | 69 | 69 | 62 | 0.635 | 0.973 |
| | 135.91 | 72 | 80 | 53 | 70 | 68 | 65 | * | 0.951 |
| | 180.18 | 75 | 81 | 65 | 52 | 56 | 52 | * | 0.512 |
| | 158.44 | 70 | 76 | 59 | 50 | 55 | 52 | 0.268 | 0.268 |
| sum | 1240.93 | 581 | 636 | 492 | 447 | 453 | 427 | 1.292 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 3e (bass). Stars(*) indicate missing values.

|  | freq |  | intensity |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 134.23 | 83 | 95 | 82 | 83 | * | * | 0.224 | 0.502 |
|  | 125.35 | 83 | 91 | 79 | 79 | * | * | 0.239 | 0.394 |
|  | 117.19 | 76 | 85 | 76 | 83 | * | * | 0.537 | 0.712 |
|  | 92.07 | 56 | 83 | 71 | 76 | * | * | 0.690 | 1.054 |
|  | 102.41 | 70 | 88 | 77 | 81 | * | * | 0.307 | 0.738 |
|  | 95.29 | 61 | 86 | 73 | 77 | * | * | 0.232 | 0.351 |
|  | 106.08 | 71 | 86 | 75 | 78 | * | * | 0.227 | 1.231 |
|  | 115.02 | 69 | 86 | 70 | 74 | * | * | 4.795 | 0.548 |
| sum | 887.63 | 569 | 700 | 603 | 631 | 0 | 0 | 7.251 | 5.530 |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| /a/ | 94.86 | 72 | 95 | 76 | 81 | * | * | 0.411 | 0.192 |
|  | 92.01 | 70 | 93 | 73 | 77 | * | * | 0.208 | 0.243 |
|  | 85.40 | 77 | 93 | 70 | 76 | * | * | 0.285 | 0.625 |
|  | 86.81 | 69 | 94 | 70 | 77 | * | * | 0.217 | 0.467 |
|  | 84.75 | 70 | 88 | 63 | 72 | * | * | 0.222 | 0.581 |
|  | 82.17 | 69 | 89 | 66 | 73 | * | * | 0.377 | 0.597 |
|  | 92.43 | 69 | 94 | 72 | 75 | * | * | 0.334 | 0.401 |
|  | 89.89 | 69 | 94 | 73 | 77 | * | * | 0.300 | 0.362 |
| sum | 708.31 | 565 | 740 | 563 | 608 | 0 | 0 | 2.354 | 3.468 |
|  |  |  |  |  |  |  |  |  |  |
| /u/ | 121.36 | 83 | 92 | 86 | 75 | 76 | 46 | 0.485 | 0.816 |
|  | 100.42 | 73 | 89 | 87 | 71 | 74 | 44 | 0.711 | 0.679 |
|  | 120.00 | 83 | 93 | 86 | 74 | 76 | 49 |  |  |
|  | 115.86 | 74 | 88 | 88 | 69 | 75 | 48 | 0.257 | 0.231 |
|  | 108.11 | 72 | 89 | 86 | 68 | 74 | 41 | 0.485 | 0.822 |
|  | 105.22 | 69 | 85 | 85 | 85 | 75 | 45 | 0.367 | 0.474 |
|  | 123.89 | 81 | 89 | 85 | 85 | 76 | 45 | 2.602 | 0.584 |
|  | 133.04 | 76 | 89 | 86 | 75 | 75 | 46 | 3.769 | 0.440 |
| sum | 927.90 | 611 | 714 | 689 | 602 | 601 | 364 | 8.676 | 0.573 |
|  |  |  |  |  |  |  |  |  |  |

Raw data of spoken vowels from subject 4e (bass). Stars(*) indicate missing values.

| | | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Frames | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 38.00 | 79 | 75 | 69 | 70 | 59 | 48 | 2.071 | 0.307 |
| | 27.00 | 75 | 75 | 62 | 63 | 46 | 38 | 1.067 | 0.223 |
| | 14.00 | 75 | 70 | 66 | 65 | 49 | 41 | 0.306 | 0.451 |
| | 47.00 | 75 | 67 | 65 | 62 | 49 | 41 | 1.689 | 0.264 |
| | 36.00 | 77 | 76 | 68 | 68 | 57 | 43 | 1.552 | 0.341 |
| | 45.00 | 75 | 74 | 71 | 68 | 55 | 38 | 1.187 | 0.260 |
| | 27.00 | 74 | 68 | 67 | 67 | 52 | 41 | 0.863 | 0.258 |
| | 55.00 | 76 | 73 | 70 | 65 | 51 | 41 | 1.984 | 0.270 |
| sum | 289.00 | 606 | 578 | 538 | 528 | 418 | 331 | 10.719 | 2.374 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 40.00 | 71 | 87 | 89 | 66 | 63 | 58 | 0.314 | 0.186 |
| | 65.00 | 71 | 86 | 83 | 64 | 61 | 55 | 0.313 | 0.151 |
| | 23.00 | 66 | 78 | 83 | 70 | 61 | 57 | 0.410 | 0.335 |
| | 57.00 | 71 | 80 | 83 | 68 | 60 | 58 | 0.338 | 0.271 |
| | 33.00 | 71 | 75 | 80 | 69 | 57 | 52 | 0.401 | 0.246 |
| | 52.00 | 72 | 73 | 81 | 66 | 56 | 48 | 0.284 | 0.154 |
| | 34.00 | 70 | 73 | 86 | 68 | 61 | 56 | 0.278 | 0.138 |
| | 50.00 | 69 | 79 | 86 | 71 | 60 | 59 | 0.229 | 0.153 |
| sum | 354.00 | 561 | 631 | 671 | 542 | 479 | 443 | 2.567 | 1.634 |
| | | | | | | | | | |
| /u/ | 29.00 | 79 | 80 | 63 | 49 | 47 | 39 | 0.653 | 0.163 |
| | 35.00 | 76 | 77 | 57 | 48 | 41 | * | 0.282 | 0.151 |
| | 21.00 | 77 | 75 | 67 | 54 | 52 | 40 | 0.496 | 0.209 |
| | 41.00 | 75 | 76 | 63 | 51 | 47 | * | 0.363 | 0.123 |
| | 25.00 | 80 | 82 | 61 | 62 | 58 | 41 | 0.735 | 0.185 |
| | 42.00 | 77 | 78 | 59 | 53 | 49 | * | 0.385 | 0.142 |
| | 25.00 | 77 | 80 | 61 | 51 | 49 | * | 0.313 | 0.151 |
| | 42.00 | 76 | 76 | 59 | 50 | 45 | * | 0.340 | 0.151 |
| sum | 260.00 | 617 | 624 | 490 | 418 | 388 | 120 | 3.567 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 6e (alto). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 211.71 | 74 | 74 | 58 | 58 | 61 | 34 | 1.930 | 0.750 |
| | 197.53 | 73 | 73 | 58 | 56 | 53 | 32 | 1.534 | 0.393 |
| | 226.04 | 76 | 76 | 60 | 60 | 50 | 33 | 2.399 | 0.500 |
| | 233.16 | 78 | 78 | 59 | 59 | 52 | 35 | 2.651 | 0.365 |
| | 210.27 | 77 | 77 | 56 | 62 | 48 | 39 | 2.030 | 0.375 |
| | 220.71 | 79 | 79 | 59 | 57 | 49 | 29 | 0.956 | 0.275 |
| | 247.10 | 78 | 78 | 60 | 58 | 45 | 36 | 1.665 | 0.441 |
| | 219.12 | 75 | 75 | 62 | 58 | 50 | 34 | 1.872 | 0.305 |
| sum | 1765.64 | 610 | 610 | 472 | 468 | 408 | 272 | 15.037 | 3.404 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 185.10 | 72 | 73 | 78 | 49 | 47 | 35 | 0.470 | 0.328 |
| | 190.05 | 72 | 71 | 73 | 53 | 43 | 30 | 0.542 | 0.262 |
| | 208.98 | 67 | 71 | 77 | 52 | 43 | * | 0.508 | 0.344 |
| | 208.22 | 71 | 71 | 71 | 53 | 39 | * | 0.455 | 0.309 |
| | 192.29 | 74 | 71 | 72 | 55 | 47 | * | 1.092 | 0.499 |
| | 193.68 | 73 | 74 | 72 | 53 | 51 | * | 0.413 | 0.280 |
| | 242.77 | 74 | 82 | 86 | 59 | 43 | * | 0.607 | 0.454 |
| | 200.21 | 70 | 70 | 73 | 55 | 48 | * | 0.601 | 0.456 |
| sum | 1621.30 | 573 | 583 | 602 | 429 | 361 | 65 | 4.688 | 2.932 |
| | | | | | | | | | |
| /u/ | 202.72 | 74 | 67 | 54 | 40 | 43 | * | 0.809 | 0.162 |
| | 219.13 | 78 | 71 | 55 | 37 | 46 | * | 0.625 | 0.139 |
| | 227.17 | 77 | 74 | 54 | 39 | 48 | * | 0.676 | 0.121 |
| | 245.85 | 80 | 74 | 58 | 42 | 44 | * | 0.655 | 0.109 |
| | 233.05 | 80 | 71 | 47 | 47 | 51 | * | 0.647 | 0.423 |
| | 229.43 | 79 | 66 | 41 | 43 | 46 | * | 0.499 | 0.134 |
| | 247.93 | 79 | 75 | 60 | 39 | 50 | * | 0.996 | 0.251 |
| | 209.78 | 72 | 61 | 47 | 40 | 42 | * | 0.402 | 0.128 |
| sum | 1815.05 | 619 | 559 | 416 | 327 | 370 | 0 | 5.309 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 7e (soprano). Stars(*) indicate missing values.

|  | freq |  | intensity |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 276.59 | 85 | 85 | 66 | 69 | 69 | * | 4.584 | 0.612 |
|  | 219.01 | 76 | 76 | 55 | 49 | 53 | * | 3.172 | 0.452 |
|  | 286.34 | 76 | 76 | 61 | 58 | 63 | * | 1.209 | 0.330 |
|  | 267.00 | 68 | 68 | 57 | 56 | 58 | * | 0.767 | 0.309 |
|  | 290.02 | 81 | 81 | 59 | 59 | 56 | * | 1.105 | 0.530 |
|  | 207.45 | 75 | 75 | 50 | 46 | 49 | * | 0.756 | 0.243 |
|  | 317.80 | 79 | 79 | 54 | 57 | 54 | * | 1.079 | 0.415 |
|  | 240.04 | 73 | 73 | 52 | 52 | 50 | * | 0.842 | 0.348 |
| sum | 2104.25 | 613 | 613 | 454 | 446 | 452 | 0 | 13.514 | 3.239 |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| /a/ | 289.00 | 69 | 74 | 78 | 55 | 53 | * |  | 0.361 |
|  | 251.23 | 63 | 66 | 72 | 51 | 49 | * | 2.814 | 1.245 |
|  | 223.05 | 69 | 71 | 76 | 52 | 48 | * | 2.568 | 0.868 |
|  | 196.92 | 74 | 77 | 76 | 53 | 48 | * | 0.788 | 0.943 |
|  | 219.81 | 71 | 64 | 72 | 51 | 45 | * | 2.084 | 1.266 |
|  | 207.38 | 71 | 57 | 67 | 49 | 42 | * | 0.711 | 0.470 |
|  | 215.20 | 73 | 78 | 82 | 56 | 52 | * | 1.200 | 0.719 |
|  | 216.17 | 72 | 69 | 69 | 52 | 50 | * | 0.870 | 0.785 |
| sum | 1818.75 | 562 | 556 | 592 | 419 | 387 | 0 | 11.035 | 6.657 |
|  |  |  |  |  |  |  |  |  |  |
| /u/ | 285.31 | 81 | 53 | 56 | 45 | 44 | * | 0.786 | 0.193 |
|  | 219.16 | 78 | 68 | 51 | 37 | 42 | * | 0.761 | 0.194 |
|  | 293.53 | 83 | 63 | 58 | 45 | 44 | * | 2.067 | 0.453 |
|  | 249.29 | 71 | 56 | 52 | 42 | 42 | * | 0.837 | 0.275 |
|  | 244.34 | 80 | 60 | 45 | 46 | 49 | * | 0.887 | 0.210 |
|  | 221.31 | 76 | 59 | 45 | 49 | 44 | * | 1.049 | 0.327 |
|  | 324.80 | 86 | 66 | 64 | 51 | 49 | * | 1.470 | 0.330 |
|  | 248.71 | 70 | 63 | 53 | 41 | 38 | * | 1.469 | 0.391 |
| sum | 2086.44 | 625 | 488 | 424 | 356 | 352 | 0 | 9.326 | 0.573 |
|  |  |  |  |  |  |  |  |  |  |

Raw data of spoken vowels from subject 8e (soprano). Stars(*) indicate missing values.

| | freq | intensity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 140.72 | 74 | 78 | 57 | 55 | 50 | 42 | 0.274 | 0.262 |
| | 143.51 | 72 | 78 | 60 | 54 | 48 | 34 | 0.669 | 0.181 |
| | 177.39 | 75 | 76 | 55 | 53 | 54 | 32 | 0.477 | 0.304 |
| | 167.82 | 73 | 74 | 53 | 52 | 51 | 29 | 0.478 | 0.235 |
| | 167.54 | 74 | 74 | 48 | 46 | 53 | 33 | 0.778 | 0.370 |
| | 157.88 | 72 | 74 | 56 | 53 | 50 | 31 | 0.688 | 0.251 |
| | 182.01 | 75 | 77 | 55 | 59 | 55 | 33 | 1.820 | 0.427 |
| | 171.09 | 72 | 74 | 56 | 52 | 47 | 42 | 0.855 | 0.307 |
| sum | 1307.96 | 587 | 605 | 440 | 424 | 408 | 276 | 6.039 | 2.337 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 126.07 | 65 | 78 | 77 | 59 | 56 | 43 | 0.434 | 0.204 |
| | 126.96 | 70 | 73 | 72 | 53 | 50 | 41 | 0.529 | 0.342 |
| | 159.79 | 71 | 79 | 80 | 57 | 46 | 42 | 0.506 | 0.498 |
| | 140.66 | 68 | 73 | 70 | 49 | 44 | 41 | 0.338 | 0.426 |
| | 168.43 | 71 | 72 | 73 | 56 | 55 | 40 | 0.304 | 0.352 |
| | 135.11 | 70 | 73 | 72 | 55 | 48 | 41 | 0.377 | 0.332 |
| | 159.70 | 73 | 79 | 79 | 57 | 52 | 40 | 0.337 | 0.657 |
| | 155.75 | 68 | 74 | 74 | 54 | 46 | 46 | 0.346 | 0.312 |
| sum | 1172.46 | 556 | 601 | 597 | 440 | 397 | 334 | 3.171 | 3.123 |
| | | | | | | | | | |
| /u/ | 165.52 | 77 | 84 | 65 | 42 | 46 | 37 | 0.662 | 0.140 |
| | 146.25 | 74 | 83 | 63 | 41 | 41 | 33 | 0.300 | 0.172 |
| | 199.43 | 79 | 82 | 57 | 45 | 45 | 41 | 0.166 | 0.120 |
| | 167.58 | 79 | 85 | 67 | 43 | 43 | 36 | 0.465 | 0.113 |
| | 155.91 | 76 | 81 | 47 | 58 | 55 | 31 | 0.420 | 0.336 |
| | 156.09 | 76 | 81 | 58 | 50 | 49 | 38 | 0.310 | 0.287 |
| | 194.18 | 78 | 81 | 60 | 49 | 46 | 40 | 0.425 | 0.427 |
| | 169.04 | 77 | 82 | 57 | 44 | 46 | 36 | 0.294 | 0.161 |
| sum | 1353.99 | 616 | 659 | 474 | 372 | 371 | 292 | 3.042 | 1.756 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 9e (tenor). Stars(*) indicate missing values.

| | freq | | intensity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| vowel | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| /i/ | 229.89 | 78 | 74 | 66 | 63 | 54 | 42 | 2.722 | 0.257 |
| | 218.41 | 78 | 74 | 61 | 59 | 48 | 40 | 1.467 | 0.265 |
| | 236.64 | 79 | 65 | 62 | 61 | 43 | 39 | 1.188 | 0.357 |
| | 251.93 | 79 | 72 | 70 | 64 | 56 | 44 | 0.580 | 0.345 |
| | 241.20 | 78 | 73 | 63 | 66 | 57 | 40 | 0.364 | 0.312 |
| | 240.96 | 78 | 70 | 58 | 63 | 47 | 43 | 1.131 | 0.317 |
| | 255.28 | 77 | 68 | 63 | 73 | 52 | 43 | 0.930 | 0.293 |
| | 219.78 | 74 | 70 | 63 | 60 | 50 | 42 | 3.833 | 0.503 |
| sum | 1894.09 | 621 | 566 | 506 | 509 | 407 | 333 | 12.215 | 2.649 |
| | | | | | | | | | |
| | | | | | | | | | |
| /a/ | 218.24 | 76 | 81 | 74 | 58 | 56 | * | 1.202 | 0.394 |
| | 203.37 | 76 | 82 | 75 | 54 | 52 | * | 0.574 | 0.312 |
| | 241.40 | 76 | 81 | 85 | 63 | 53 | * | 1.403 | 0.645 |
| | 228.28 | 77 | 81 | 78 | 61 | 52 | * | 0.680 | 0.325 |
| | 214.00 | 76 | 75 | 76 | 59 | 38 | * | 1.208 | 0.997 |
| | 209.65 | 76 | 74 | 70 | 55 | 46 | * | 0.426 | 0.385 |
| | 239.30 | 77 | 85 | 81 | 64 | 58 | * | 0.605 | 0.662 |
| | 230.24 | 73 | 75 | 74 | 57 | 48 | * | 0.413 | 0.294 |
| sum | 1784.49 | 607 | 634 | 613 | 471 | 403 | 0 | 6.511 | 4.014 |
| | | | | | | | | | |
| /u/ | 248.88 | 80 | 80 | 73 | 48 | 44 | 37 | 1.009 | 0.334 |
| | 232.42 | 81 | 81 | 77 | 46 | 41 | 38 | 0.500 | 0.171 |
| | 272.53 | 79 | 79 | 74 | 52 | 49 | * | 0.533 | 0.243 |
| | 252.12 | 81 | 81 | 75 | 49 | 47 | * | 0.614 | 0.148 |
| | 258.30 | 82 | 82 | 72 | 52 | 48 | * | 0.664 | 0.252 |
| | 233.87 | 81 | 81 | 79 | 55 | 50 | * | 0.642 | 0.143 |
| | 261.27 | 79 | 79 | 71 | 43 | 37 | * | 0.450 | 0.313 |
| | 214.75 | 77 | 77 | 75 | 40 | 36 | * | 0.127 | 0.228 |
| sum | 1974.12 | 640 | 640 | 596 | 385 | 352 | 75 | 4.539 | 0.573 |
| | | | | | | | | | |

Raw data of spoken vowels from subject 10e (alto). Stars(*) indicate missing values.

| % range | vowel | freq | | intensity | | | | | | jitter | shimmer |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | | | |
| 10% | /i/ | 129.94 | 76.00 | 80.00 | 70.00 | 66.00 | * | * | | 1.715 | 0.899 |
| | /a/ | 131.44 | 73.00 | 81.00 | 76.00 | 62.00 | 64.00 | * | | 0.484 | 0.434 |
| | /u/ | 127.94 | 72.00 | 83.00 | 69.00 | 52.00 | 51.00 | * | | 0.512 | 0.224 |
| mean | | 129.77 | 73.67 | 81.33 | 71.67 | 60.00 | 57.50 | | | 0.904 | 0.519 |
| sd | | 1.22 | 1.56 | 1.11 | 2.89 | 5.33 | 6.50 | | | 0.541 | 0.253 |
| 25% | /i/ | 167.78 | 76.00 | 82.00 | 62.00 | 64.00 | * | * | | 2.965 | 0.516 |
| | /a/ | 163.80 | 77.00 | 85.00 | 81.00 | 66.00 | * | * | | 0.639 | 0.360 |
| | /u/ | 167.04 | 74.00 | 85.00 | 67.00 | 49.00 | * | * | | 0.214 | 0.214 |
| mean | | 166.21 | 75.67 | 84.00 | 70.00 | 59.67 | | | | 1.273 | 0.363 |
| sd | | 1.60 | 1.11 | 1.33 | 7.33 | 7.11 | | | | 1.128 | 0.102 |
| 50% | /i/ | 242.46 | 79.00 | 79.00 | 64.00 | 64.00 | 61.00 | * | | 0.872 | 0.491 |
| | /a/ | 238.79 | 78.00 | 83.00 | 77.00 | 54.00 | 58.00 | * | | 0.908 | 0.241 |
| | /u/ | 245.08 | 79.00 | 79.00 | 79.00 | 55.00 | 52.00 | * | | 0.833 | 0.245 |
| mean | | 242.11 | 78.67 | 80.33 | 73.33 | 57.67 | 57.00 | | | 0.871 | 0.326 |
| sd | | 2.21 | 0.44 | 1.78 | 6.22 | 4.22 | 3.33 | | | 0.025 | 0.110 |
| 90% | /i/ | 431.94 | 91.00 | 91.00 | 67.00 | 62.00 | 55.00 | * | | 1.151 | 0.260 |
| | /a/ | 431.91 | 87.00 | 82.00 | * | * | 53.00 | 53.00 | | 0.947 | 0.141 |
| | /u/ | 442.89 | 93.00 | 93.00 | 76.00 | 47.00 | 52.00 | * | | 2.291 | 0.079 |
| mean | | 435.58 | 90.33 | 88.67 | 71.50 | 54.50 | 53.33 | 53.00 | | 1.463 | 0.160 |
| sd | | 4.87 | 2.22 | 4.44 | 4.50 | 7.50 | 1.11 | 0.00 | | 0.552 | 0.067 |
| overall | mean | 243.42 | 79.58 | 83.58 | 71.64 | 58.27 | 55.75 | 53.00 | | 1.128 | 0.342 |
| | sd | 96.36 | 5.38 | 3.28 | 5.60 | 6.25 | 3.94 | 0.00 | | 0.602 | 0.165 |

Raw data of sung vowels from subject 1c (tenor). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 201.11 | 72.00 | 44.00 | 43.00 | 36.00 | * | * | 1.064 | 0.312 |
| | /a/ | 196.17 | 70.00 | 68.00 | 65.00 | * | 46.00 | 45.00 | 0.739 | 0.499 |
| | /u/ | 197.40 | 72.00 | 75.00 | 50.00 | * | 35.00 | * | 0.716 | 0.143 |
| mean | | 198.22 | 71.33 | 62.33 | 52.67 | 36.00 | 40.50 | 45.00 | 0.840 | 0.318 |
| sd | | 1.92 | 0.89 | 12.22 | 8.22 | 0.00 | 5.50 | 0.00 | 0.150 | 0.121 |
| 25% | /i/ | 251.62 | 74.00 | 74.00 | 38.00 | 46.00 | 38.00 | * | 0.862 | 0.207 |
| | /a/ | 248.69 | 74.00 | 69.00 | 62.00 | * | 41.00 | 44.00 | 1.411 | 0.494 |
| | /u/ | 247.26 | 73.00 | 73.00 | 54.00 | 47.00 | * | * | 1.093 | 0.191 |
| mean | | 249.19 | 73.67 | 72.00 | 51.33 | 46.50 | 39.50 | 44.00 | 1.122 | 0.297 |
| sd | | 1.62 | 0.44 | 2.00 | 8.89 | 0.50 | 1.50 | 0.00 | 0.193 | 0.131 |
| 50% | /i/ | 290.65 | 80.00 | 80.00 | 48.00 | 41.00 | 40.00 | * | 1.077 | 0.214 |
| | /a/ | 286.96 | 73.00 | 66.00 | 55.00 | * | 37.00 | * | 1.075 | 0.369 |
| | /u/ | 296.36 | 80.00 | 80.00 | 51.00 | 35.00 | | * | 0.852 | 0.123 |
| mean | | 291.32 | 77.67 | 75.33 | 51.33 | 38.00 | 38.50 | | 1.001 | 0.235 |
| sd | | 3.36 | 3.11 | 6.22 | 2.44 | 3.00 | 1.50 | | 0.100 | 0.089 |
| 90% | /i/ | 383.84 | 83.00 | 83.00 | 57.00 | 60.00 | 46.00 | 50.00 | 0.486 | 0.184 |
| | /a/ | 377.77 | 78.00 | 81.00 | 79.00 | 46.00 | 54.00 | 50.00 | 1.975 | 0.280 |
| | /u/ | 385.04 | 85.00 | 85.00 | 68.00 | 49.00 | * | * | 0.549 | 0.077 |
| mean | | 382.22 | 82.00 | 83.00 | 68.00 | 51.67 | 50.00 | 50.00 | 1.003 | 0.180 |
| sd | | 2.97 | 2.67 | 1.33 | 7.33 | 5.56 | 4.00 | 0.00 | 0.648 | 0.069 |
| overall | mean | 280.24 | 76.17 | 73.17 | 55.83 | 45.00 | 42.13 | 47.25 | 0.992 | 0.258 |
| | sd | 56.53 | 4.19 | 7.64 | 8.64 | 5.75 | 4.91 | 2.75 | 0.291 | 0.111 |

Raw data of sung vowels from from subject 2c (soprano). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 89.57 | 62.00 | 69.00 | 52.00 | 57.00 | 43.00 | * | 0.964 | 0.646 |
| | /a/ | 87.95 | 61.00 | 72.00 | 71.00 | 51.00 | 46.00 | 44.00 | 0.488 | 0.741 |
| | /u/ | 88.69 | 61.00 | 68.00 | 52.00 | 34.00 | 38.00 | 37.00 | 0.323 | 0.346 |
| mean | | 88.74 | 61.33 | 69.67 | 58.33 | 47.33 | 42.33 | 40.50 | 0.592 | 0.578 |
| sd | | 0.55 | 0.44 | 1.56 | 8.44 | 8.89 | 2.89 | 3.50 | 0.248 | 0.154 |
| | | | | | | | | | | |
| 25% | /i/ | 111.55 | 70.00 | 68.00 | * | 45.00 | 39.00 | 28.00 | 0.649 | 0.323 |
| | /a/ | 108.864. | 66.00 | 68.00 | 42.00 | 42.00 | 44.00 | 34.00 | 1.359 | 0.578 |
| | /u/ | 108.38 | 67.00 | 72.00 | 54.00 | 40.00 | 32.00 | * | 0.210 | 0.138 |
| mean | | 109.97 | 67.67 | 69.33 | 48.00 | 42.33 | 38.33 | 31.00 | 0.739 | 0.346 |
| sd | | 1.59 | 1.56 | 1.78 | 6.00 | 1.78 | 4.22 | 3.00 | 0.413 | 0.154 |
| | | | | | | | | | | |
| 50% | /i/ | 129.37 | 74.00 | 77.00 | 66.00 | 61.00 | 52.00 | 31.00 | 2.513 | 0.362 |
| | /a/ | 129.69 | 67.00 | 84.00 | 73.00 | 59.00 | 54.00 | 29.00 | 0.265 | 0.342 |
| | /u/ | 132.00 | 74.00 | 78.00 | 62.00 | 41.00 | 40.00 | 42.00 | * | * |
| mean | | 130.35 | 71.67 | 79.67 | 67.00 | 53.67 | 48.67 | 34.00 | 1.389 | 0.352 |
| sd | | 1.10 | 3.11 | 2.89 | 4.00 | 8.44 | 5.78 | 5.33 | 1.124 | 0.010 |
| | | | | | | | | | | |
| 90% | /i/ | 177.01 | 77.00 | 76.00 | 56.00 | 53.00 | 44.00 | 32.00 | 0.397 | 0.243 |
| | /a/ | 173.37 | 75.00 | 69.00 | 61.00 | 51.00 | 39.00 | 47.00 | 0.289 | 0.410 |
| | /u/ | 172.00 | 77.00 | 81.00 | 59.00 | 46.00 | 36.00 | 33.00 | * | * |
| mean | | 174.13 | 76.33 | 75.33 | 58.67 | 50.00 | 39.67 | 37.33 | 0.343 | 0.327 |
| sd | | 1.92 | 0.89 | 4.22 | 1.78 | 2.67 | 2.89 | 6.44 | 0.054 | 0.084 |
| | | | | | | | | | | |
| overall | mean | 127.24 | 69.25 | 73.50 | 58.91 | 48.33 | 42.25 | 35.70 | 0.746 | 0.413 |
| | sd | 27.28 | 5.25 | 4.75 | 7.01 | 7.00 | 4.92 | 5.44 | 0.520 | 0.145 |

Raw data of sung vowels from from subject 3c (bass). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 110.69 | 71.00 | 75.00 | 64.00 | 68.00 | 43.00 | 31.00 | 1.482 | 1.268 |
| | /a/ | 113.59 | 70.00 | 80.00 | 78.00 | 62.00 | 60.00 | 43.00 | 0.739 | 0.499 |
| | /u/ | 110.13 | 69.00 | 75.00 | 55.00 | 53.00 | 49.00 | 23.00 | 0.169 | 0.227 |
| mean | | 111.47 | 70.00 | 76.67 | 65.67 | 61.00 | 50.67 | 32.33 | 0.797 | 0.665 |
| sd | | 1.41 | 0.67 | 2.22 | 8.22 | 5.33 | 6.22 | 7.11 | 0.457 | 0.402 |
| 25% | /i/ | 129.08 | 72.00 | 75.00 | 68.00 | 68.00 | 40.00 | 42.00 | 0.182 | 0.390 |
| | /a/ | 131.92 | 72.00 | 85.00 | 84.00 | 62.00 | 55.00 | 28.00 | 0.227 | 0.274 |
| | /u/ | 127.26 | 72.00 | 77.00 | 70.00 | 70.00 | 51.00 | * | 0.169 | 0.227 |
| mean | | 129.42 | 72.00 | 79.00 | 74.00 | 66.67 | 48.67 | 35.00 | 0.193 | 0.297 |
| sd | | 1.67 | 0.00 | 4.00 | 6.67 | 3.11 | 5.78 | 7.00 | 0.023 | 0.062 |
| 50% | /i/ | 161.94 | 77.00 | 77.00 | 66.00 | 67.00 | 51.00 | 53.00 | 0.540 | 0.276 |
| | /a/ | 161.57 | 75.00 | 86.00 | 88.00 | 69.00 | 45.00 | 32.00 | 0.297 | 0.206 |
| | /u/ | 163.05 | 77.00 | 83.00 | 68.00 | 64.00 | 45.00 | 37.00 | 0.299 | 0.194 |
| mean | | 162.19 | 76.33 | 82.00 | 74.00 | 66.67 | 47.00 | 40.67 | 0.379 | 0.225 |
| sd | | 0.58 | 0.89 | 3.33 | 9.33 | 1.78 | 2.67 | 8.22 | 0.108 | 0.034 |
| 90% | /i/ | 218.19 | 80.00 | 71.00 | 67.00 | 63.00 | 66.00 | 55.00 | 0.486 | 0.258 |
| | /a/ | 213.60 | 79.00 | 89.00 | 88.00 | 67.00 | 48.00 | 37.00 | 0.333 | 0.190 |
| | /u/ | 222.13 | 81.00 | 75.00 | 69.00 | 58.00 | 49.00 | 38.00 | 0.421 | 0.118 |
| mean | | 217.98 | 80.00 | 78.33 | 74.67 | 62.67 | 54.33 | 43.33 | 0.413 | 0.189 |
| sd | | 2.91 | 0.67 | 7.11 | 8.89 | 3.11 | 7.78 | 7.78 | 0.054 | 0.047 |
| overall | mean | 155.26 | 74.58 | 79.00 | 72.08 | 64.25 | 50.17 | 38.09 | 0.445 | 0.344 |
| | sd | 34.82 | 3.58 | 4.67 | 8.28 | 3.92 | 5.36 | 7.39 | 0.244 | 0.188 |

Raw data of sung vowels from from subject 4c (bass). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 158.45 | 77.00 | 85.00 | 76.00 | 61.00 | 49.00 | 43.00 | 0.306 | 0.193 |
| | /a/ | 158.00 | 76.00 | 84.00 | 62.00 | 60.00 | 53.00 | 47.00 | * | * |
| | /u/ | 158.00 | 77.00 | 85.00 | 66.00 | 52.00 | 47.00 | * | * | * |
| mean | | 158.15 | 76.67 | 84.67 | 68.00 | 57.67 | 49.67 | 45.00 | 0.306 | 0.193 |
| sd | | 0.20 | 0.44 | 0.44 | 5.33 | 3.78 | 2.22 | 2.00 | 0.000 | 0.000 |
| 25% | /i/ | 197.05 | 80.00 | 85.00 | 63.00 | 57.00 | 60.00 | 49.00 | 1.207 | 0.263 |
| | /a/ | 194.48 | 79.00 | 85.00 | 69.00 | 62.00 | 51.00 | 42.00 | 0.394 | 0.413 |
| | /u/ | 200.00 | 81.00 | 87.00 | 62.00 | 48.00 | 54.00 | * | 0.325 | 0.126 |
| mean | | 197.18 | 80.00 | 85.67 | 64.67 | 55.67 | 55.00 | 45.50 | 0.642 | 0.267 |
| sd | | 1.88 | 0.67 | 0.89 | 2.89 | 5.11 | 3.33 | 3.50 | 0.377 | 0.097 |
| 50% | /i/ | 229.82 | 81.00 | 81.00 | 64.00 | 62.00 | 60.00 | 46.00 | 1.331 | 0.338 |
| | /a/ | 229.54 | 81.00 | 91.00 | 83.00 | 59.00 | 51.00 | 42.00 | 0.288 | 0.115 |
| | /u/ | 231.55 | 82.00 | 82.00 | 68.00 | 50.00 | 55.00 | * | 0.506 | 0.117 |
| mean | | 230.30 | 81.33 | 84.67 | 71.67 | 57.00 | 55.33 | 44.00 | 0.708 | 0.190 |
| sd | | 0.83 | 0.44 | 4.22 | 7.56 | 4.67 | 3.11 | 2.00 | 0.415 | 0.099 |
| 90% | /i/ | 263.66 | 84.00 | 84.00 | 74.00 | 62.00 | 68.00 | 61.00 | 2.030 | 0.316 |
| | /a/ | 262.83 | 82.00 | 87.00 | 80.00 | 60.00 | 57.00 | 52.00 | 0.459 | 0.233 |
| | /u/ | 262.07 | 85.00 | 82.00 | 71.00 | 48.00 | 65.00 | 48.00 | 1.176 | 0.137 |
| mean | | 262.85 | 83.67 | 84.33 | 75.00 | 56.67 | 63.33 | 53.67 | 1.222 | 0.229 |
| sd | | 0.54 | 1.11 | 1.78 | 3.33 | 5.78 | 4.22 | 4.89 | 0.539 | 0.061 |
| overall | mean | 212.12 | 80.42 | 84.83 | 69.83 | 56.75 | 55.83 | 47.78 | 0.802 | 0.225 |
| | sd | 34.46 | 2.18 | 1.86 | 5.81 | 4.83 | 5.14 | 4.20 | 0.507 | 0.088 |

Raw data of sung vowels from from subject 5c (tenor). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 197.63 | 68.00 | 73.00 | * | 53.00 | 54.00 | 52.00 | 0.473 | 0.238 |
| | /a/ | 193.73 | 65.00 | 71.00 | 72.00 | 52.00 | 46.00 | 30.00 | 0.374 | 0.297 |
| | /u/ | 196.65 | 68.00 | 74.00 | 49.00 | 40.00 | 40.00 | 26.00 | 0.362 | 0.121 |
| mean | | 196.00 | 67.00 | 72.67 | 60.50 | 48.33 | 46.67 | 36.00 | 0.403 | 0.219 |
| sd | | 1.52 | 1.33 | 1.11 | 11.50 | 5.56 | 4.89 | 10.67 | 0.047 | 0.065 |
| 25% | /i/ | 246.19 | 73.00 | 73.00 | * | 60.00 | 59.00 | 49.00 | 0.629 | 0.331 |
| | /a/ | 242.20 | 70.00 | 76.00 | 78.00 | 57.00 | 49.00 | 32.00 | 0.451 | 0.229 |
| | /u/ | 245.46 | 74.00 | 74.00 | 71.00 | 40.00 | 45.00 | 48.00 | 0.451 | 0.126 |
| mean | | 244.61 | 72.33 | 74.33 | 74.50 | 52.33 | 51.00 | 43.00 | 0.510 | 0.229 |
| sd | | 1.61 | 1.56 | 1.11 | 3.50 | 8.22 | 5.33 | 7.33 | 0.079 | 0.068 |
| 50% | /i/ | 388.18 | 84.00 | 67.00 | * | 60.00 | 62.00 | 44.00 | 0.743 | 0.170 |
| | /a/ | 385.61 | 78.00 | 81.00 | 79.00 | * | 62.00 | 48.00 | 0.786 | 0.269 |
| | /u/ | 392.18 | 84.00 | 84.00 | 73.00 | 40.00 | 46.00 | 42.00 | 0.639 | 0.080 |
| mean | | 388.66 | 82.00 | 77.33 | 76.00 | 50.00 | 56.67 | 44.67 | 0.723 | 0.173 |
| sd | | 2.35 | 2.67 | 6.89 | 3.00 | 10.00 | 7.11 | 2.22 | 0.056 | 0.064 |
| 90% | /i/ | 486.40 | 78.00 | 78.00 | 59.00 | 63.00 | * | 32.00 | 0.554 | 0.283 |
| | /a/ | * | 66.00 | * | 80.00 | 53.00 | 49.00 | 43.00 | * | * |
| | /u/ | 485.76 | 80.00 | * | 70.00 | * | 49.00 | * | 0.607 | 0.120 |
| mean | | 486.08 | 74.67 | 78.00 | 69.67 | 58.00 | 49.00 | 37.50 | 0.581 | 0.202 |
| sd | | 0.32 | 5.78 | 0.00 | 7.11 | 5.00 | 0.00 | 5.50 | 0.027 | 0.082 |
| overall | mean | 314.54 | 74.00 | 75.10 | 70.11 | 51.80 | 51.00 | 40.55 | 0.552 | 0.206 |
| | sd | 102.80 | 5.67 | 3.72 | 7.19 | 7.08 | 6.00 | 7.67 | 0.118 | 0.075 |

Raw data of sung vowels from from subject 6c (alto). Stars(*) indicate missing values.

| % range | vowel | freq | intensity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 267.22 | 96.00 | 96.00 | 81.00 | 79.00 | 79.00 | * | 1.084 | 0.273 |
| | /a/ | 262.48 | 92.00 | 98.00 | 91.00 | 72.00 | 71.00 | * | 0.536 | 0.331 |
| | /u/ | 266.32 | 95.00 | 95.00 | 84.00 | 58.00 | 66.00 | * | 0.520 | 0.201 |
| mean | | 265.34 | 94.33 | 96.33 | 85.33 | 69.67 | 72.00 | | 0.713 | 0.268 |
| sd | | 1.91 | 1.56 | 1.11 | 3.78 | 7.78 | 4.67 | | 0.247 | 0.045 |
| 25% | /i/ | 327.70 | 101.00 | 101.00 | 83.00 | 77.00 | 83.00 | * | 1.036 | 0.227 |
| | /a/ | 323.77 | 96.00 | 103.00 | 101.00 | 59.00 | 75.00 | * | 0.594 | 0.252 |
| | /u/ | 329.31 | 100.00 | 100.00 | 90.00 | 65.00 | 69.00 | * | 0.584 | 0.081 |
| mean | | 326.93 | 99.00 | 101.33 | 91.33 | 67.00 | 75.67 | | 0.738 | 0.187 |
| sd | | 2.10 | 2.00 | 1.11 | 6.44 | 6.67 | 4.89 | | 0.199 | 0.070 |
| 50% | /i/ | 476.00 | 106.00 | * | 89.00 | 88.00 | 83.00 | 67.00 | 0.155 | 0.173 |
| | /a/ | 473.70 | 105.00 | * | 108.00 | 70.00 | 85.00 | 79.00 | 0.678 | 0.152 |
| | /u/ | 476.87 | 115.00 | * | 106.00 | 67.00 | 77.00 | 73.00 | 0.986 | 0.102 |
| mean | | 475.52 | 108.67 | | 101.00 | 75.00 | 81.67 | 73.00 | 0.606 | 0.142 |
| sd | | 1.21 | 4.22 | | 8.00 | 8.67 | 3.11 | 4.00 | 0.301 | 0.027 |
| 90% | /i/ | 978.00 | 122.00 | * | 89.00 | 84.00 | 69.00 | 67.00 | * | * |
| | /a/ | 979.00 | 123.00 | * | 123.00 | 93.00 | 86.00 | 74.00 | * | * |
| | /u/ | 974.00 | 125.00 | * | 85.00 | 84.00 | 79.00 | 70.00 | * | * |
| mean | | 977.00 | 123.33 | | 99.00 | 87.00 | 78.00 | 70.33 | | |
| sd | | 2.00 | 1.11 | | 16.00 | 4.00 | 6.00 | 2.44 | | |
| overall | mean | 511.20 | 106.33 | 98.83 | 94.17 | 74.67 | 76.83 | 71.67 | 0.686 | 0.199 |
| | sd | 232.90 | 9.94 | 2.50 | 10.22 | 9.50 | 5.69 | 3.67 | 0.233 | 0.064 |

Raw data of sung vowels from from subject 7c (soprano). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10 | /i/ | 175.31 | 71.00 | 71.00 | * | 44.00 | 48.00 | | 0.705 | 0.270 |
| | /a/ | 172.37 | 71.00 | 71.00 | 67.00 | 51.00 | * | | 0.695 | 0.470 |
| | /u/ | 174.75 | 70.00 | 76.00 | 55.00 | * | * | | 0.429 | 0.175 |
| | mean | 174.14 | 70.67 | 72.67 | 61.00 | 47.50 | 48.00 | | 0.610 | 0.305 |
| | sd | 1.18 | 0.44 | 2.22 | 6.00 | 3.50 | 0.00 | | 0.120 | 0.110 |
| 25 | /i/ | 218.67 | 76.00 | 76.00 | 58.00 | 55.00 | 50.00 | | 1.432 | 0.339 |
| | /a/ | 218.37 | 73.00 | 75.00 | 73.00 | 56.00 | 46.00 | | 0.408 | 0.323 |
| | /u/ | 216.18 | 75.00 | 75.00 | 65.00 | 42.00 | 39.00 | | 0.436 | 0.154 |
| | mean | 217.74 | 74.67 | 75.33 | 65.33 | 51.00 | 45.00 | | 0.759 | 0.272 |
| | sd | 1.04 | 1.11 | 0.44 | 5.11 | 6.00 | 4.00 | | 0.449 | 0.079 |
| 50 | /i/ | 260.97 | 77.00 | 77.00 | 67.00 | 62.00 | 57.00 | | 2.355 | 0.292 |
| | /a/ | 260.87 | 76.00 | 79.00 | 78.00 | 54.00 | 46.00 | | 0.488 | 0.302 |
| | /u/ | 259.96 | 79.00 | 79.00 | 66.00 | 51.00 | 39.00 | | 0.394 | 0.143 |
| | mean | 260.60 | 77.33 | 78.33 | 70.33 | 55.67 | 47.33 | | 1.079 | 0.246 |
| | sd | 0.42 | 1.11 | 0.89 | 5.11 | 4.22 | 6.44 | | 0.851 | 0.068 |
| 90 | /i/ | 433.47 | 92.00 | 92.00 | 60.00 | 57.00 | 42.00 | | 0.846 | 0.113 |
| | /a/ | 439.53 | 79.00 | 79.00 | 77.00 | | | | 1.148 | 0.420 |
| | /u/ | 438.92 | 91.00 | 91.00 | 78.00 | | 43.00 | | 0.914 | 0.099 |
| | mean | 437.30 | 87.33 | 87.33 | 71.67 | 57.00 | 42.50 | | 0.969 | 0.211 |
| | sd | 2.56 | 5.56 | 5.56 | 7.78 | 0.00 | 0.50 | | 0.119 | 0.140 |
| overall | mean | 272.45 | 77.50 | 78.42 | 67.64 | 52.44 | 45.56 | | 0.854 | 0.258 |
| | sd | 82.43 | 5.17 | 4.65 | 6.45 | 4.84 | 4.27 | | 0.405 | 0.101 |

Raw data of sung vowels from subject 10c (alto). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 158.98 | 74.00 | 82.00 | 65.00 | 67.00 | 61.00 | 50.00 | 0.812 | 0.337 |
| | /a/ | 156.72 | 72.00 | 88.00 | 84.00 | 64.00 | 66.00 | 65.00 | 0.438 | 0.586 |
| | /u/ | 166.07 | 73.00 | 84.00 | 70.00 | 58.00 | 64.00 | * | 0.576 | 0.402 |
| mean | | 160.59 | 73.00 | 84.67 | 73.00 | 63.00 | 63.67 | 57.50 | 0.609 | 0.442 |
| sd | | 3.65 | 0.67 | 2.22 | 7.33 | 3.33 | 1.78 | 7.50 | 0.136 | 0.096 |
| | | | | | | | | | | |
| 25% | /i/ | 195.55 | 77.00 | 86.00 | 71.00 | 67.00 | 67.00 | 52.00 | 1.816 | 0.529 |
| | /a/ | 194.05 | 74.00 | 95.00 | 85.00 | 67.00 | 71.00 | 48.00 | 0.356 | 0.273 |
| | /u/ | 189.03 | 76.00 | 92.00 | 76.00 | 64.00 | 75.00 | * | 0.710 | 0.282 |
| mean | | 192.88 | 75.67 | 91.00 | 77.33 | 66.00 | 71.00 | 50.00 | 0.961 | 0.361 |
| sd | | 2.56 | 1.11 | 3.33 | 5.11 | 1.33 | 2.67 | 2.00 | 0.570 | 0.112 |
| | | | | | | | | | | |
| 50% | /i/ | 261.83 | 81.00 | 81.00 | 68.00 | 70.00 | 58.00 | 52.00 | 2.648 | 0.711 |
| | /a/ | 262.59 | 77.00 | 95.00 | 89.00 | 73.00 | 72.00 | 68.00 | 0.843 | 0.323 |
| | /u/ | 264.92 | 81.00 | 90.00 | 80.00 | 69.00 | 71.00 | 39.00 | 1.172 | 0.271 |
| mean | | 263.11 | 79.67 | 88.67 | 79.00 | 70.67 | 67.00 | 53.00 | 1.554 | 0.435 |
| sd | | 1.20 | 1.78 | 5.11 | 7.33 | 1.56 | 6.00 | 10.00 | 0.729 | 0.184 |
| | | | | | | | | | | |
| 90% | /i/ | 361.56 | 83.00 | 103.00 | 93.00 | 67.00 | 69.00 | 58.00 | 0.615 | 0.202 |
| | /a/ | 351.14 | 88.00 | 85.00 | 69.00 | 72.00 | 70.00 | 60.00 | 1.522 | 0.263 |
| | /u/ | 362.17 | 89.00 | 89.00 | 91.00 | 64.00 | 68.00 | 51.00 | 0.646 | 0.165 |
| mean | | 358.29 | 86.67 | 92.33 | 84.33 | 67.67 | 69.00 | 56.33 | 0.928 | 0.210 |
| sd | | 4.77 | 2.44 | 7.11 | 10.22 | 2.89 | 0.67 | 3.56 | 0.396 | 0.035 |
| | | | | | | | | | | |
| overall | mean | 243.72 | 78.75 | 89.17 | 78.42 | 66.83 | 67.67 | 54.30 | 1.013 | 0.362 |
| | sd | 66.98 | 4.71 | 4.86 | 8.58 | 2.89 | 3.72 | 6.76 | 0.518 | 0.130 |

Raw data of sung vowels from from subject 2e (tenor). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 119.52 | 75.00 | 84.00 | 82.00 | 80.00 | 76.00 | * | 0.388 | 0.693 |
| | /a/ | 117.68 | 74.00 | 93.00 | 86.00 | 79.00 | 82.00 | 80.00 | 0.288 | 0.680 |
| | /u/ | 119.80 | 77.00 | 84.00 | 75.00 | 71.00 | 76.00 | 71.00 | 0.294 | 0.489 |
| mean | | 119.00 | 75.33 | 87.00 | 81.00 | 76.67 | 78.00 | 75.50 | 0.323 | 0.621 |
| sd | | 0.88 | 1.11 | 4.00 | 4.00 | 3.78 | 2.67 | 4.50 | 0.043 | 0.088 |
| | | | | | | | | | | |
| 25% | /i/ | 141.17 | 77.00 | 90.00 | 88.00 | 89.00 | 83.00 | * | 0.452 | 0.445 |
| | /a/ | 140.12 | 78.00 | 95.00 | 89.00 | 85.00 | 90.00 | 86.00 | 0.315 | 0.336 |
| | /u/ | 142.30 | 78.00 | 93.00 | 83.00 | 80.00 | 84.00 | 79.00 | 0.780 | 0.209 |
| mean | | 141.19 | 77.67 | 92.67 | 86.67 | 84.67 | 85.67 | 82.50 | 0.516 | 0.330 |
| sd | | 0.73 | 0.44 | 1.78 | 2.44 | 3.11 | 2.89 | 3.50 | 0.176 | 0.081 |
| | | | | | | | | | | |
| 50% | /i/ | 191.47 | 79.00 | 97.00 | 90.00 | 92.00 | 89.00 | 63.00 | 0.422 | 0.305 |
| | /a/ | 190.36 | 79.00 | 100.00 | 91.00 | 89.00 | 90.00 | 86.00 | 0.371 | 0.271 |
| | /u/ | 191.51 | 79.00 | 94.00 | 90.00 | 87.00 | 87.00 | 82.00 | 0.852 | 0.123 |
| mean | | 191.12 | 79.00 | 97.00 | 90.33 | 89.33 | 88.67 | 77.00 | 0.548 | 0.233 |
| sd | | 0.50 | 0.00 | 2.00 | 0.44 | 1.78 | 1.11 | 9.33 | 0.202 | 0.073 |
| | | | | | | | | | | |
| 90% | /i/ | 324.78 | 99.00 | 99.00 | 89.00 | 89.00 | 86.00 | 53.00 | 0.459 | 0.511 |
| | /a/ | 322.41 | 95.00 | 112.00 | 107.00 | 88.00 | 89.00 | 94.00 | 0.511 | 0.227 |
| | /u/ | 324.74 | 96.00 | 96.00 | 111.00 | 87.00 | 92.00 | * | 0.642 | 0.234 |
| mean | | 323.98 | 96.67 | 102.33 | 102.33 | 88.00 | 89.00 | 73.50 | 0.537 | 0.324 |
| sd | | 1.05 | 1.56 | 6.44 | 8.89 | 0.67 | 2.00 | 20.50 | 0.070 | 0.125 |
| | | | | | | | | | | |
| overall | mean | 193.82 | 82.17 | 94.75 | 90.08 | 84.67 | 85.33 | 77.11 | 0.481 | 0.377 |
| | sd | 65.08 | 7.25 | 5.08 | 6.46 | 4.78 | 4.28 | 9.85 | 0.143 | 0.156 |

Raw data of sung vowels from from subject 3e (bass). Stars(*) indicate missing values.

| % range | vowel | freq |  |  | intensity |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 79.21 | 87.00 | 96.00 | 85.00 | 88.00 | 93.00 | 45.00 | 0.600 | 0.568 |
|  | /a/ | 80.44 | 82.00 | 99.00 | 94.00 | 96.00 | 85.00 | * | 0.695 | 0.470 |
|  | /u/ | 80.18 | 81.00 | 98.00 | 93.00 | 86.00 | 90.00 | 47.00 | 0.214 | 0.319 |
| mean |  | 79.94 | 83.33 | 97.67 | 90.67 | 90.00 | 89.33 | 46.00 | 0.503 | 0.452 |
| sd |  | 0.49 | 2.44 | 1.11 | 3.78 | 4.00 | 2.89 | 1.00 | 0.193 | 0.089 |
| 25% | /i/ | 107.29 | 96.00 | 98.00 | 94.00 | 99.00 | 78.00 | 48.00 | 0.407 | 0.456 |
|  | /a/ | 107.39 | 90.00 | 102.00 | 95.00 | 96.00 | 99.00 | 93.00 | 0.213 | 0.322 |
|  | /u/ | 108.04 | 78.00 | 105.00 | 99.00 | 94.00 | 96.00 | 90.00 | 0.369 | 0.327 |
| mean |  | 107.57 | 88.00 | 101.67 | 96.00 | 96.33 | 91.00 | 77.00 | 0.330 | 0.368 |
| sd |  | 0.31 | 6.67 | 2.44 | 2.00 | 1.78 | 8.67 | 19.33 | 0.078 | 0.058 |
| 50% | /i/ | 260.97 | 95.00 | 95.00 | 85.00 | 80.00 | 75.00 | 56.00 | 2.355 | 0.292 |
|  | /a/ | 260.87 | 94.00 | 97.00 | 96.00 | 72.00 | 64.00 | 56.00 | 0.488 | 0.302 |
|  | /u/ | 259.96 | 97.00 | 97.00 | 84.00 | 69.00 | 57.00 | 56.00 | 0.394 | 0.143 |
| mean |  | 260.60 | 95.33 | 96.33 | 88.33 | 73.67 | 65.33 | 56.00 | 1.079 | 0.246 |
| sd |  | 0.42 | 1.11 | 0.89 | 5.11 | 4.22 | 6.44 | 0.00 | 0.851 | 0.068 |
| 90% | /i/ | 433.47 | 110.00 | 110.00 | 78.00 | 75.00 | 60.00 | 56.00 | 0.846 | 0.113 |
|  | /a/ | 439.53 | 97.00 | 97.00 | 95.00 | 56.00 | 56.00 | 56.00 | 1.148 | 0.420 |
|  | /u/ | 438.92 | 109.00 | 109.00 | 96.00 | 56.00 | 61.00 | 56.00 | 0.914 | 0.099 |
| mean |  | 437.30 | 105.33 | 105.33 | 89.67 | 62.33 | 59.00 | 56.00 | 0.969 | 0.211 |
| sd |  | 2.56 | 5.56 | 5.56 | 7.78 | 8.44 | 2.00 | 0.00 | 0.119 | 0.140 |
| overall | mean | 221.36 | 93.00 | 100.25 | 91.17 | 80.58 | 76.17 | 59.91 | 0.720 | 0.319 |
|  | sd | 127.60 | 7.83 | 4.17 | 5.44 | 12.58 | 14.00 | 11.49 | 0.397 | 0.108 |

Raw data of sung vowels from from subject 4e (bass). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 260.03 | 86.00 | 86.00 | 78.00 | 73.00 | 69.00 | 43.00 | 0.436 | 0.465 |
| | /a/ | 260.77 | 82.00 | 93.00 | 97.00 | 73.00 | 66.00 | 53.00 | 0.430 | 0.135 |
| | /u/ | 261.13 | 85.00 | 85.00 | 87.00 | 51.00 | 50.00 | * | 0.501 | 0.141 |
| mean | | 260.64 | 84.33 | 88.00 | 87.33 | 65.67 | 61.67 | 48.00 | 0.456 | 0.247 |
| sd | | 0.41 | 1.56 | 3.33 | 6.44 | 9.78 | 7.78 | 5.00 | 0.030 | 0.145 |
| | | | | | | | | | | |
| 25% | /i/ | 329.80 | 94.00 | 94.00 | 76.00 | 69.00 | 68.00 | 64.00 | 1.744 | 0.287 |
| | /a/ | 322.36 | 87.00 | 93.00 | 98.00 | 73.00 | 68.00 | 46.00 | 0.641 | 0.258 |
| | /u/ | 327.59 | 93.00 | 93.00 | 91.00 | 64.00 | 56.00 | 57.00 | 0.520 | 0.133 |
| mean | | 326.58 | 91.33 | 93.33 | 88.33 | 68.67 | 64.00 | 55.67 | 0.968 | 0.226 |
| sd | | 2.82 | 2.89 | 0.44 | 8.22 | 3.11 | 5.33 | 6.44 | 0.517 | 0.062 |
| | | | | | | | | | | |
| 50% | /i/ | 435.11 | 104.00 | 104.00 | 91.00 | 74.00 | 75.00 | 67.00 | 0.833 | 0.103 |
| | /a/ | 431.93 | 89.00 | 105.00 | 100.00 | 74.00 | 76.00 | 50.00 | 0.669 | 0.092 |
| | /u/ | 435.95 | 103.00 | 103.00 | 102.00 | 77.00 | 57.93 | 50.00 | 0.769 | 0.063 |
| mean | | 434.33 | 98.67 | 104.00 | 97.67 | 75.00 | 69.64 | 55.67 | 0.757 | 0.086 |
| sd | | 1.60 | 6.44 | 0.67 | 4.44 | 1.33 | 7.81 | 7.56 | 0.059 | 0.015 |
| | | | | | | | | | | |
| 90% | /i/ | 683.00 | 99.00 | 99.00 | * | 77.00 | 75.00 | 50.00 | * | * |
| | /a/ | 681.00 | 108.00 | 108.00 | 103.00 | 75.00 | 60.00 | 56.00 | * | * |
| | /u/ | 680.00 | 110.00 | * | 110.00 | 87.00 | 58.00 | 58.00 | * | * |
| mean | | 681.33 | 105.67 | 103.50 | 106.50 | 79.67 | 64.33 | 54.67 | | |
| sd | | 1.11 | 4.44 | 4.50 | 3.50 | 4.89 | 7.11 | 3.11 | | |
| | | | | | | | | | | |
| overall | mean | 425.72 | 95.00 | 96.64 | 93.91 | 72.25 | 64.91 | 54.00 | 0.727 | 0.186 |
| | sd | 132.11 | 8.17 | 6.51 | 8.46 | 5.46 | 7.10 | 5.82 | 0.259 | 0.100 |

Raw data of sung vowels from from subject 6e (alto). Stars(*) indicate missing values.

| % range | vowel | freq |  |  | intensity |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10 | /i/ | 167.63 | 67.00 | 80.00 | 69.00 | * | 64.00 | 47.00 | 0.831 | 0.270 |
|  | /a/ | 164.54 | 68.00 | 89.00 | * | 69.00 | 64.00 | 43.00 | 0.407 | 0.298 |
|  | /u/ | 168.00 | 69.00 | 80.00 | 68.00 | * | 45.00 | 45.00 | * | * |
| mean |  | 166.72 | 68.00 | 83.00 | 68.50 | 69.00 | 57.67 | 45.00 | 0.619 | 0.284 |
| sd |  | 1.45 | 0.67 | 4.00 | 0.50 | 0.00 | 8.44 | 1.33 | 0.212 | 0.014 |
| 25 | /i/ | 224.55 | 71.00 | 74.00 | * | 71.00 | 69.00 | 42.00 | 1.673 | 0.538 |
|  | /a/ | 219.76 | 71.00 | 88.00 | * | * | 66.00 | 45.00 | 0.451 | 0.229 |
|  | /u/ | 227.47 | 73.00 | * | 65.00 | * | 52.00 | 51.00 | 0.476 | 0.104 |
| mean |  | 223.92 | 71.67 | 81.00 | 65.00 | 71.00 | 62.33 | 46.00 | 0.867 | 0.290 |
| sd |  | 2.78 | 0.89 | 7.00 | 0.00 | 0.00 | 6.89 | 3.33 | 0.538 | 0.165 |
| 50 | /i/ | 327.46 | 83.00 | 83.00 | * | 73.00 | 69.00 | 43.00 | 0.623 | 0.338 |
|  | /a/ | 328.67 | 78.00 | * | 91.00 | 69.00 | 69.00 | 45.00 | 1.146 | 0.329 |
|  | /u/ | 334.41 | 86.00 | 86.00 | 82.00 | * | 65.00 | 56.00 | 0.740 | 0.083 |
| mean |  | 330.18 | 82.33 | 84.50 | 86.50 | 71.00 | 67.67 | 48.00 | 0.836 | 0.250 |
| sd |  | 2.82 | 2.89 | 1.50 | 4.50 | 2.00 | 1.78 | 5.33 | 0.206 | 0.111 |
| 90 | /i/ | 560.00 | 91.00 | * | * | 73.00 | 63.00 | * | * | * |
|  | /a/ | 516.00 | 83.00 | * | 89.00 | * | 78.00 | 71.00 | * | * |
|  | /u/ | 563.00 | 94.00 | * | 90.00 | * | 68.00 | 75.00 | * | * |
| mean |  | 546.33 | 89.33 |  | 89.50 | 73.00 | 69.67 | 73.00 |  |  |
| sd |  | 20.22 | 4.22 |  | 0.50 | 0.00 | 5.56 | 2.00 |  |  |
| overall | mean | 316.79 | 77.83 | 82.86 | 79.14 | 71.00 | 64.33 | 51.18 | 0.793 | 0.274 |
|  | sd | 121.47 | 8.00 | 4.16 | 10.12 | 1.60 | 5.61 | 8.81 | 0.317 | 0.102 |

Raw data of sung vowels from from subject 7e(soprano). Stars(*) indicate missing values.

| % range | vowel | freq |  |  | intensity |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 219.94 | 81.00 | 81.00 | 62.00 | 63.00 | 64.00 | * | 5.928 | 0.523 |
|  | /a/ | 214.37 | 77.00 | 77.00 | 64.00 | 62.00 | 60.00 | * | 0.577 | 0.154 |
|  | /u/ | 230.67 | 81.00 | * | 78.00 | * | * | * | 0.617 | 0.139 |
| mean |  | 221.66 | 79.67 | 79.00 | 68.00 | 62.50 | 62.00 |  | 2.374 | 0.272 |
| sd |  | 6.01 | 1.78 | 2.00 | 6.67 | 0.50 | 2.00 |  | 2.369 | 0.167 |
| 25% | /i/ | 288.89 | 86.00 | 86.00 | 64.00 | * | 61.00 | * | 0.969 | 0.388 |
|  | /a/ | 281.00 | 80.00 | 79.00 | 80.00 | 60.00 | 64.00 | * | 1.099 | 0.438 |
|  | /u/ | 298.52 | 86.00 | 86.00 | 71.00 | 37.50 | 48.00 | * | 1.099 | 0.438 |
| mean |  | 289.47 | 84.00 | 83.67 | 71.67 | 48.75 | 57.67 |  | 1.056 | 0.421 |
| sd |  | 6.03 | 2.67 | 3.11 | 5.56 | 11.25 | 6.44 |  | 0.058 | 0.022 |
| 50% | /i/ | 470.01 | 94.00 | * | 54.00 | 59.00 | 56.00 | * | 1.182 | 0.119 |
|  | /a/ | 464.83 | 84.00 | * | 88.00 | 54.00 | 59.00 | * | 1.473 | 0.170 |
|  | /u/ | 473.18 | 98.00 | * | 77.00 | 44.00 | 49.00 | * | 1.289 | 0.097 |
| mean |  | 469.34 | 92.00 |  | 73.00 | 52.33 | 54.67 |  | 1.315 | 0.129 |
| sd |  | 3.01 | 5.33 |  | 12.67 | 5.56 | 3.78 |  | 0.106 | 0.028 |
| 90% | /i/ | 898.00 | 104.00 | 76.00 | 64.00 | 64.00 | 57.00 | 56.00 | * | * |
|  | /a/ | 888.00 | 99.00 | 62.00 | 54.00 | 69.00 | 53.00 | * | * | * |
|  | /u/ | * | * | * | * | * | * | * | * | * |
| mean |  | 893.00 | 101.50 | 69.00 | 59.00 | 66.50 | 55.00 | 56.00 |  |  |
| sd |  | 5.00 | 2.50 | 7.00 | 5.00 | 2.50 | 2.00 | 0.00 |  |  |
| overall | mean | 429.76 | 88.18 | 78.14 | 68.73 | 56.94 | 57.10 | 56.00 | 1.581 | 0.274 |
|  | sd | 190.04 | 7.69 | 5.55 | 9.16 | 7.85 | 4.50 | 0.00 | 0.966 | 0.154 |

Raw data of sung vowels from from subject 8e (soprano). Stars(*) indicate missing values.

| % range | vowel | freq | intensity | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10% | /i/ | 123.80 | 68.00 | 75.00 | 68.00 | 64.00 | * | * | 1.434 | 0.933 |
| | /a/ | 122.25 | 67.00 | 80.00 | 77.00 | 68.00 | 69.00 | * | 0.256 | 0.381 |
| | /u/ | 123.48 | 69.00 | 77.00 | 70.00 | 48.00 | 55.00 | * | 0.357 | 0.724 |
| mean | | 123.18 | 68.00 | 77.33 | 71.67 | 60.00 | 62.00 | | 0.682 | 0.679 |
| sd | | 0.62 | 0.67 | 1.78 | 3.56 | 8.00 | 7.00 | | 0.501 | 0.199 |
| 25% | /i/ | 144.01 | 70.00 | 78.00 | 71.00 | 71.00 | * | * | 0.242 | 0.251 |
| | /a/ | 145.74 | 69.00 | 82.00 | 78.00 | 70.00 | 70.00 | * | 0.383 | 0.305 |
| | /u/ | 145.00 | 71.00 | 80.00 | 73.00 | 54.00 | 57.00 | * | * | * |
| mean | | 144.92 | 70.00 | 80.00 | 74.00 | 65.00 | 63.50 | | 0.313 | 0.278 |
| sd | | 0.60 | 0.67 | 1.33 | 2.67 | 7.33 | 6.50 | | 0.071 | 0.027 |
| 50% | /i/ | 218.20 | 80.00 | 80.00 | 74.00 | 63.00 | 69.00 | * | 1.888 | 0.488 |
| | /a/ | 218.63 | 78.00 | 92.00 | 87.00 | 55.00 | 75.00 | 76.00 | 0.571 | 0.276 |
| | /u/ | 220.29 | 83.00 | 86.00 | 78.00 | 53.00 | 59.00 | * | 0.491 | 0.141 |
| mean | | 219.04 | 80.33 | 86.00 | 79.67 | 57.00 | 67.67 | 76.00 | 0.983 | 0.302 |
| sd | | 0.83 | 1.78 | 4.00 | 4.89 | 4.00 | 5.78 | 0.00 | 0.603 | 0.124 |
| 90% | /i/ | 342.65 | 88.00 | 91.00 | 69.00 | 52.00 | 64.00 | * | 0.638 | 0.146 |
| | /a/ | 350.24 | 85.00 | 97.00 | 93.00 | 53.00 | 61.00 | 63.00 | 0.613 | 0.138 |
| | /u/ | 351.28 | 95.00 | 95.00 | 87.00 | 57.00 | 56.00 | * | 0.639 | 0.127 |
| mean | | 348.06 | 89.33 | 94.33 | 83.00 | 54.00 | 60.33 | 63.00 | 0.630 | 0.137 |
| sd | | 3.60 | 3.78 | 2.22 | 9.33 | 2.00 | 2.89 | 0.00 | 0.011 | 0.007 |
| overall | mean | 208.80 | 76.92 | 84.42 | 77.08 | 59.00 | 63.50 | 69.50 | 0.683 | 0.355 |
| | sd | 74.75 | 7.92 | 6.49 | 6.26 | 6.83 | 5.90 | 6.50 | 0.356 | 0.201 |

Raw data of sung vowels from from subject 9e (tenor). Stars(*) indicate missing values.

| % range | vowel | freq | | | intensity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Fo | Fo | f1 | f2 | f3 | f4 | f5 | jitter | shimmer |
| 10 | /i/ | 175.90 | 79.00 | 86.00 | 70.00 | * | 62.00 | 42.00 | 1.003 | 0.419 |
| | /a/ | 173.39 | 78.00 | 91.00 | 87.00 | 71.00 | 65.00 | 45.00 | 0.239 | 0.182 |
| | /u/ | 173.25 | 80.00 | 89.00 | 81.00 | 59.00 | 47.00 | 40.00 | 0.368 | 0.231 |
| mean | | 174.18 | 79.00 | 88.67 | 79.33 | 65.00 | 58.00 | 42.33 | 0.537 | 0.277 |
| sd | | 1.15 | 0.67 | 1.78 | 6.22 | 6.00 | 7.33 | 1.78 | 0.311 | 0.094 |
| 25 | /i/ | 216.19 | 84.00 | 85.00 | 77.00 | * | 71.00 | 46.00 | 0.959 | 0.239 |
| | /a/ | 209.53 | 82.00 | * | 89.00 | 72.00 | 67.00 | 45.00 | 0.370 | 0.224 |
| | /u/ | 222.52 | 84.00 | * | 92.00 | 54.00 | * | 41.00 | 0.337 | 0.213 |
| mean | | 216.08 | 83.33 | 85.00 | 86.00 | 63.00 | 69.00 | 44.00 | 0.555 | 0.225 |
| sd | | 4.37 | 0.89 | 0.00 | 6.00 | 9.00 | 2.00 | 2.00 | 0.269 | 0.009 |
| 50 | /i/ | 320.82 | 88.00 | 88.00 | 78.00 | 73.00 | 51.00 | 46.00 | 1.238 | 0.429 |
| | /a/ | 302.62 | 84.00 | 85.00 | 87.00 | * | 69.00 | 68.00 | 0.575 | 0.297 |
| | /u/ | 321.00 | 91.00 | 91.00 | 76.00 | * | 58.00 | 49.00 | 0.740 | 0.083 |
| mean | | 314.81 | 87.67 | 88.00 | 80.33 | 73.00 | 59.33 | 54.33 | 0.851 | 0.270 |
| sd | | 8.13 | 2.44 | 2.00 | 4.44 | 0.00 | 6.44 | 9.11 | 0.258 | 0.124 |
| 90 | /i/ | 474.14 | 102.00 | * | 78.00 | * | 66.00 | 54.00 | 0.988 | 0.117 |
| | /a/ | 539.00 | 97.00 | * | 104.00 | * | 72.00 | 70.00 | * | * |
| | /u/ | 527.00 | 101.00 | * | 110.00 | * | 71.00 | 54.00 | * | * |
| mean | | 513.38 | 100.00 | | 97.33 | | 69.67 | 59.33 | 0.988 | 0.117 |
| sd | | 26.16 | 2.00 | | 12.89 | | 2.44 | 7.11 | 0.000 | 0.000 |
| overall | mean | 304.61 | 87.50 | 87.86 | 85.75 | 65.80 | 63.55 | 50.00 | 0.682 | 0.243 |
| | sd | 109.81 | 6.92 | 2.16 | 9.08 | 7.44 | 6.58 | 7.67 | 0.304 | 0.083 |

Raw data of sung vowels from from subject 10e (alto). Stars(*) indicate missing values.

# REFERENCES

Akerlund, L., Gramming, P., & Sundberg, J., (1992). Phonetogram and averages of sound pressure levels and fundamental frequencies of speech: Comparison between female singers and nonsingers, J. of Voice, 6(1), 55-63.

Allen, E. L., & Hollien, H., A., (1973). Laminagraphic study of pulse (vocal fry) register phonation, Folia Phoniatrica, 25, 241-250.

Aronson, M., & Aronson, A., (1990). SAS® System: A programmers guide, New York: McGraw- Hill.

Awan, S. N., (1991). Phonetographic profiles and $F_0$-SPL characteristics of untrained versus trained vocal groups, J. of Voice, 5(1), 41-30.

Awan, S. N., (1993). Superimposition of speaking voice characteristics and phonetograms in trained and untrained vocal groups, J. of Voice, 7(1), 30-37.

Baken, R.J., (1987). Clinical measurement of speech and voice, Boston: College Hill.

Baken, R. J., (1991). An overview of laryngeal function for voice production, in Sataloff, R.T., (Ed.) Professional voice: The science and art of clinical care.(pp. 30-31) New York: Raven Press.

Bouhuys, A., Proctor, D., & Mead, J. (1966). Kinetic aspects of singing, J. Applied Physiol., 21(2), 483-496.

Britto, A., & Doyle, P. A., (1990). Comparison of habitual and derived optimal voice fundamental frequency values in normal young adult speakers J. Speech and Hearing Disorders, 55, 476-84.

Brown, W. S., Jr., Hunt, E., & Williams, W. N., (1988). Physiological differences between the trained and untrained speaking and singing voice, J. of Voice, 2, 102-110

Brown, W. S., Jr., Morris, R. J., Hicks, D., & Howell, E., (1993). Phonational profiles of female professional singers and nonsingers, J. of Voice, 5(4) 219-226

Brown, W. S., Jr., Morris, R. J., Hollien, H., & Howell, E., (1991). Speaking fundamental frequency Characteristics as a function of age and professional Singing, J. of Voice, 5(4) 310-315

Brown, W. S., Jr., Morris, R. J., & Michel, J. F., (1989). Vocal jitter in young adult and aged, female voices, J. of Voice, 3(2) 113-119.

Brown, W. S., Jr., Morris, R. J., & Michel, J. F., (1990). Vocal jitter and fundamental frequency characteristics in aged, female professional singers, J. of Voice, 4(2) 135-141.

Brown, W. S., Jr., Rothman, H. B., & Williams, W. N., (1978). Physiological differentiation between singers and nonsingers, Transcripts of the seventh symposium on care of the professional voice, New York: Voice Foundation, 45-7

Coleman, R. F., Mabis, J. H., & Hinson, J. K., (1977). Fundamental frequency-sound pressure level profiles of adult male and female voices. JSHR, 20, 107-204

Colton, R. H., (1973). Vocal intensity in modal and falsetto registers, Folia Phoniat., 25, 62-70

Deal, R. E., & Emanuel, F. W., (1978). Some waveform and spectral features of vowel roughness, JSHR, 21, 250-264

Denes, P. B., & Pinson, E. N., (1963) The speech chain, Garden City, NY: Anchor Press/Doubleday.

Doherty, T. E., & Shipp, T., (1988). Tape recorder effects on jitter and shimmer extraction. JSHR, 31, 485-490.

Fletcher, H., (1934). Loudness, pitch and the timber of musical tones and their relation to the intensity, the frequency, and the overtone structure. J of Acoust. Soc. of Am, 6, 59-69

Gould, W., (1977). The effect of voice training on lung volumes in singers and the possible relationship to the damping factor of Pressman J. of Research in Singing, 1(1), 3-15

Gramming, P, & Sundberg, J , (1988a). Spectrum factors relevant to phonetogram measurement, J of Acoust. Soc. of Am, 83(6), 2352-2360

Gramming, P, Sundberg, J., Ternström, S., Leandersson, & R., Perkins, W. (1988b). Relationship between changes in voce pitch and loudness. J. of Voice, 2, 118-26.

Hecker, M., & Kreul, E., (1971). Descriptions of the speech of patients with cancer of the vocal folds. Part I: measures of fundamental frequency J of Acoust. Soc. of Am, 49, 1275-1282

Hirano, M., (1981). Clinical examination of voice, New York:Springer- Verlag.

Hollien, H , (1974). On vocal registers, J. of Phonetics, 2, 125-143

Hollien, H , (1983). The puzzle of the singers formant; in Vocal fold physiology, edited by D. M. Bless and J. H. Abbs, San Diego:College-Hill.

Hollien, H., & Jackson, B., (1973). Normative data on the speaking fundamental characteristics of young adult males, J. of Phonetics, 1, 117-120

Hollien, H., & Keister, E. (1978). Pilot data on frequency abilities of singers and nonsingers;J. of Research in Singing, 1(2), 15-23

Hollien, H., & Michel, J., (1968). Vocal fry as a phonational register, JSHR, 11, 600-604

Hollien, H., Michel, J., & Doherty, E., (1978). A method for analyzing vocal jitter in sustained phonation, J. of Phonetics, 1, 85-91

Hollien, H., & Paul, P., (1969). A second evaluation of the speaking fundamental speaking characteristics of post-adolescent girls, Language and Speech, 12, 119-124

Honjo, I., & Isshiki, N., (1980). Laryngosdopic and voice characteristics of aged persons, Archives of Otolaryngology, 106, 149-150

Horii, Y., (1975). Some statistical characteristics of voice fundamental frequency, JSHR, 18, 192-201

Horii, Y., (1979). Fundamental frequency perturbation observed in sustained phonation JSHR , 22, 5-19.

Horii, Y., (1980). Vocal shimmer in sustained phonation JSHR;23, 202-209.

Horii, Y., (1982). Jitter and shimmer differences among sustained vowel phonations, JSHR, 25, 12-18

Jacob, L. A., (1968). A normative study of laryngeal jitter, Unpublished masters thesis, University of Kansas, 1968.

Karnell, M. P., (1991), Laryngeal perturbation analysis: minimum length of analysis window, JSHR, 34, 544-548.

Koike, Y., (1973). Application of some acoustic measures for the evaluation of laryngeal dysfunction, Studia Phonologica, 7, 17-23.

Koike, Y., Takahashi, H., & Calcaterra, T. C., (1977). Acoustic measures for detecting laryngeal pathology, Acta Otolaryngologica, 84, 105-117.

Lieberman, P., (1961). Perturbations in vocal pitch, J of Acoust. Soc. of Am. 33, 597-603

Lieberman, P., (1963). Some acoustic measures of the fundamental periodicity of normal and pathologic larynges, J of Acoust. Soc. of Am. 35, 344-353

Michel, J. F., & Wendahl, R., (1971). Correlates of voice production. In Travis, L. E. (Ed.) Handbook of speech pathology , Englewood Cliffs, NJ:Prentice-Hall, Chap. 18, pp. 465-480.

Miller, R., (1992). How singing is not like speech, The NATS Journal, May/June, 26.

Miller, R., & Franco, J. C., (1992). A brief spectral study of vowel differentiation and modification in a professional tenor voice, The NATS Journal, Nov./Dec., 21-22.

Miller, R., & Franco, J. C., (1991). Spectrographic analysis of the singing voice, The NATS Journal, Sept./Oct, 32-34.

Murry, T., (1988). Vocal tract Parameters associated with voice quality and preference, J. of Voice, 2(2), 111-117

Murry, T., Brown, W., & Rothman, H. B., (1988). Judgments of voice quality and preference: acoustic interpretations, J. of Voice, 1(3), 252-257

Murry, T., (1990). Pitch matching accuracy in singers and nonsingers, J. of Voice, 4(4), 317-321

Murry, T., Caligiuri, M., (1989). Phonatory and nonphonatory control in singers and nonsingers, J of Voice, 3, 257-63

Murry, T., Large, J., (1979). Frequency perturbation in singers, Transcripts of the eighth symposium on care of the professional voice, New York: Voice Foundation, 36-41.

Murry, T., Large, J., & Daldaard, J., (1979). Vocal jitter in sung and spoken vowels., J. of Research in Singing, 2(1), 28-43

Murry T., & Zwirner, P., (1991). Pitch matching ability of experienced and inexperienced singers, J. of Voice, 5(3), 197-202

Peterson, G. E., & Barney, H. L., (1952) Control methods used in a study of the vowels, J. Acoust. Soc. Am., 32(2), 693-703.

Sataloff, R. T., (1981). Professional singers: the science and art of clinical care. Am. J. of Otolaryngology, 2(3), 251-266.

Sataloff, R. T., (1991). Professional voice: the science and art of clinical care, New York:Raven Press

Schutte, H. K., & Miller, R., (1983). Differences in spectral analysis of a trained and an untrained singer, The NATS Journal, Nov./Dec, 12-13

Shipp, T., & Izdebski, K., (1975). Vocal frequency and vertical larynx positioning by singers and nonsingers. J. Acoust. Soc. Am., 58(5), 1104-1106.

Sorenson, D., & Horii, Y., (1984). Directional perturbation factors for jitter and for shimmer, J. of Communication Disorders, 17, 143-151.

Sorenson, D., and Horii, Y., (1983). Frequency and amplitude perturbation in the voices of female speakers, J. of Communication Disorders, 16, 57-61.

Stoicheff, M. L., (1981). Speaking fundamental frequency characteristics of nonsmoking female adults JSHR, 24, 437-441.

Sundberg, J., (1974). Articulatory interpretation of the "singing formant", J. Acoust. Soc. Am., 55(4), 838-844.

Sundberg, J.,(1990). What's so special about singers? J. of Voice, 4(2), 107-119

Sundberg , J., (1991). Vocal tract resonance, in Professional voice: the science and art of clinical care, Sataloff, R.T, ed., New York:Raven Press

Takahashi, H., & Koike, Y., (1975). Some perceptual dimensions and acoustical correlates of pathological voices, Acta Otolaryngologica, suppl., 338:1-24

Titze, I., Horii, Y., & Scherer, R.C., (1987). Some technical considerations in voice perturbation measurements. JSHR, 30, 252-260

Titze, I., & Liang, H., (1993a). Comparison of $F_0$ extraction methods for high-precision voice perturbation measurements, JSHR, 36, 1120-1133.

Titze, I., & Winholtz, W. S., (1993b) Effect of microphone type and placement on voice perturbation measurements, JSHR, 36, 1177-1190.

Watson, P., & Hixon, T., (1985), Respiratory Kinematics in classical (opera) singers, JSHR, 28, 104-122

Watson, S. (1992). Motor control in phonatory subsystems in singers and nonsingers, Master's thesis, San Diego State University, 1992.

Wilcox, K., & Horii, Y., (1980). Age and changes in vocal jitter, J. of Gerontology, 35, 194-198

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Processes and Disorders

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William

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Linda L. Difiore

Linda L. Difiore
Associate Professor of Music

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the Department of Communication Processes and Disorders in the College of Liberal Arts and Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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